ENCLOSURE F

OCEAN DISCHARGE CRITERIA EVALUATION SOUTH AND CENTRAL CALIFORNIA FOR NPDES PERMIT NO. CA 2800000

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EXECUTIVE SUMMARY

This section discusses ten factors that the EPA Regional Administrator must consider in analysis of the final NPDES general permit, including the following:

- Compliance with ocean discharge criteria contained in Section 403 of the Clean Water Act, and
- Determination that the permit will not cause unreasonable degradation of the marine environment, consistent with all limitations, conditions, and monitoring requirements in effect.

The ten factors for determining unreasonable degradation are detailed in Section 1. The sections that follow discuss the available information concerning the issues to be evaluated. This section summarizes these issues, the conditions and limitations that are included in the final NPDES general permit that ensure compliance with Section 403, and a discussion of the determination that no unreasonable degradation of the marine environment will result from discharges authorized by this permit.

Evaluation of the Ten Ocean Discharge Criteria

Factor 1 - Quantities, Composition, and Potential for Bioaccumulation or Persistence of Pollutants.

The quantities and composition of the discharged material are presented in Section 2, and the potential for bioaccumulation of contaminants associated with the discharge sources is addressed in Section 4. Specific volumes of discharged materials associated with OCS operations are not precisely known but are expected to be proportional to the numbers of wells drilled. Recent estimates by MMS indicated that approximately 40-50 development wells and 5-6 exploratory wells may be drilled during the 5-year permit period. Based on average drill mud discharges from four platforms in Santa Maria Basin during 1986 to 1994, and the predicted number of wells as noted above, discharge volumes for drill muds and cuttings could represent 52,700 m3 and 9,800 m3, respectively. These discharges would occur at the drilling sites, which are expected to be primarily in the Santa Barbara Channel and Santa Maria Basin. Consequently, these discharges would not be concentrated in one geographic location. Produced water discharge rates vary for individual platforms, with representative discharge volumes for platforms ranging from 42,000 to 840,000 gal/day. The total average produced water discharged into the Santa Barbara Channel is approximately 4.28 million gal/day.

Drill muds discharged to OCS waters consist of an approved, generic, water-based mud formulation with specialty additives. The generic, water-based muds and their primary constituents (e.g., barite and bentonite) are considered inert and essentially nontoxic to marine organisms. Discharges to the ocean of the more toxic oil-based muds are prohibited. Cuttings are comprised of crushed formation rocks that have been separated from drill muds, washed, and then discharged. Cuttings are generally considered inert and insoluble, although small amounts of drill muds may be attached to the particle surfaces. Produced waters are comprised of formation waters that are separated from recovered oil and gas, treated to remove floating oils, and then discharged or reinjected into the formation. The discharge consists of a brine containing dissolved solids, sulfur, selected metals (especially barium), and hydrocarbons at concentrations that are relatively higher than those in receiving waters. However, results from field and laboratory studies do not indicate significant potentials for contaminant bioaccumulation in organisms exposed to these types of platform discharge materials.

For discharges other than produced waters and drill muds and cuttings, the volumes of the individual waste sources are considered inconsequential, and compositions of the waste are generally free of significant amounts of persistent, biologically available, or highly toxic constituents. Regardless, the permit requires recording of the monthly discharge volumes of deck drainage, well treatment, completion, work over fluids, and sanitary waste, and annual reporting of volumes in a compliance monitoring report. Monitoring and reporting of produced water discharge volumes are also required by the permit.

The proposed NPDES permit requires that the 96 hour LC50 for the suspended particulate phase (SPP) for drill muds and cuttings discharges be equal to or greater than 30,000 ppm. Potential effects of the produced water discharges are also mitigated by the effluent limitations which are proposed for the general permit. Marine water quality criteria apply at the edge of the mixing zone and this also imposes a restriction on water quality within the mixing zone. The permit also includes proposed technology-based effluent limitations for oil and grease in produced water (29 mg/L monthly average and 42 mg/L daily max). Finally, the proposed general permit provides that individual permits may be issued, which could include additional mitigation such as a change in the location of the discharge, if necessary, to protect specific biological resources.

Factor 2 - Potential for Biological, Physical, or Chemical Transport

Section 3 of this document summarizes relevant information concerning the transport and dispersion of drill muds, cuttings, and produced water in the marine environment. In general, OCS platform wastes will be discharged below the sea surface through a disposal tube. The depth of the discharge varies for individual platforms. Dispersion, transport, and fate of the discharge constituents depends on a number of factors, including the physical/chemical properties of the material, settling velocities of the waste particles, depth of the discharge relative to the density structure of the water column and bottom depth, and chemical reactions involving waste components.

Dispersion and transport of primary platform discharge sources have been evaluated by a number of field studies and related modeling efforts. The following general conclusions have been noted regarding dispersion and transport.

- Drill muds discharged from OCS platforms may be widely dispersed over areas of a few kilometers.

- Accumulation of drill mud particles is expected to be highest near the platform and then decrease rapidly with distance from the discharge point.

- Drill muds may be widely dispersed, however, studies using barium as a conservative tracer of drill mud accumulation on the bottom indicate that a footprint is measurable only within one to two kilometers or less or the platform.

Recent studies of long-term impacts of platform operations in Santa Maria Basin also demonstrated that discharges did not result in elevated concentrations in bottom sediments of drill mud constituents other than barium (e.g., other metals and hydrocarbons). The general absence of elevated concentrations of other metals and hydrocarbons in bottom sediments was attributable to the lack of significant enrichment of other metals and potential solubility of lower molecular weight PAHs in muds.

In contrast to the drill mud discharges, cuttings particles are expected to sink rapidly to the sea floor in the immediate vicinity of the platform. Cuttings particles eventually will be buried by accumulations of natural sediments and biological mixing processes (i.e., bioturbation) or contribute to topographic features on the bottom generally referred to as shell mounds. Dispersion of produced water discharges are affected by the momentum and buoyancy of the plume, rapid dilution with entrained receiving waters, and transport by subsurface currents. Specific dilution rates for produced water plumes will vary depending on the plume properties and receiving water characteristics. Nevertheless, dilution rates from approximately 100 to more than 1,000 times are expected to occur within 100 m of the discharge point. Subsequent dispersion by mixing and currents is expected to further dilute the plume by 10 to 1,000 times within a distance of approximately 1,000 m from the discharge point. At these dilution rates, produced water constituent concentrations are expected to be reduced to levels below the respective marine water quality criteria (see factor 10 below), as well as levels considered potentially toxic to marine organisms (see factor 3 below).

Biological processes are not expected to contribute significantly to transport of platform discharges. This conclusion is based on results from field and laboratory studies that have demonstrated minimal potentials for uptake and retention of platform waste constituents by marine organisms. Minor exceptions are that sediment mixing (bioturbation) by benthic infauna may promote burial of drill mud and cuttings particles in surficial sediment layers, and microbial processes will degrade some of the less refractory hydrocarbons. Chemical processes affecting transport of platform discharges primarily consist of particle adsorption and solubilization of constituents. In general, the trace constituents of primary concern have strong affinities for particles and, therefore, the fate of these constituents will be controlled by physical processes responsible for horizontal and vertical transport of particles (e.g., currents and gravitational settling). Some of the lower molecular weight hydrocarbons in produced waters and muds are relatively more soluble in seawater. Consequently, transport and fate of these compounds will be affected by dilution and mixing processes, as well microbial and chemical degradation.

Factor 3 - Composition and Vulnerability of Biological Communities

The third factor used to determine that there is no unreasonable degradation of the marine environment is an assessment of the presence of unique species or communities of species, endangered species, or species critical to the structure or function of the ecosystem. Section 5 describes the biological community of the Southern California OCS, including the presence of endangered species and factors making these communities or species vulnerable to the permitted activities.

In general, the permit area comprises multiple marine habitat types, supports diverse and abundant marine communities, including threatened and endangered species, as well as important commercial fisheries resources. Portions of the permit area represent areas of special biological significance to marine mammals of the Southern California Bight. For example, portions of the Santa Barbara Channel, Santa Monica Basin, and San Pedro Basin represent migration pathways or areas of concentration of gray whales and other mammals. Areas in the vicinity of several of the Channel Islands also are used as seasonal hauling grounds, foraging sites, and breeding colonies by pinnipeds. Additionally, numerous unique biological environments in Central and Southern California Planning Areas, including designated areas of special biological significance, ecological reserves, natural preserves, refuges, and national marine sanctuaries, overlap with the general permit area (see Section 5).

Available information indicates that most marine organisms are not vulnerable to significant impacts from routine OCS platform discharges. As mentioned for Factor 1, exposures to constituents of platform wastes typically do not cause significant acute or sublethal effects or result in significant bioaccumulation of contaminants in marine organisms. The most likely potential impacts to organisms may include the following:

- Exposure of plankton, pelagic organisms, and fouling organisms on the platforms to produced water plumes;
- Localized smothering or fouling of benthic organisms by drill muds and cuttings; and
- Physical alteration of the substrate as a result of accumulation of cuttings and shell hash from fouling organisms attached to the platform.

Some of these potential impacts to organisms from discharges have been observed previously from field and laboratory studies. Drill muds (and the muds that adhere to cuttings) have been shown to cause smothering to some hard-bottom organisms. Produced waters and drill muds at environmentally realistic exposure levels also have been associated with some sublethal effects to larval invertebrates. However, when these results are extrapolated to OCS platform operations, the temporal and spatial scales of potential impacts are considered insignificant. It is unlikely that mobile organisms, such as fish, mammals, or birds, including threatened and endangered species, would suffer direct mortality as a result of exposure to platform discharges. Further, recent studies did not indicate that fish exposed to produced water discharges accumulated significant amounts of trace contaminants. Consequently, potentials for accumulation of contaminants in fish to levels that are potentially harmful to fish or higher trophic levels, including humans, are considered negligible.

Factor 4 - Importance of the Receiving Water to the Surrounding Biological Community

The importance of the receiving waters to the species and communities of the Southern California Planning Area is discussed in Section 5 in conjunction with the discussion of the species and biological communities. The receiving waters represent relatively small areas corresponding to zones of initial dilution for individual platform discharges. With the possible exception of fouling communities attached to the platform legs and rockfish aggregations that have been reported at OCS platforms, the receiving waters do not represent critical habitats for biological communities. The fouling communities depend on the platform structure for attachment substrate for adult organisms and, in the absence of the platform, would not occur at these offshore locations. Commercial harvesting of fouling organisms (e.g., mussels) from OCS platforms has occurred for several years. From this perspective, the productivity and of these organisms and concentrations of tissue contaminants do not appear to be significantly affected by platform operations. Previous studies have noted that OCS platforms can support substantial populations of rockfish, especially young of the year and juvenile life stages. The existing information is not sufficient to determine whether the presence of OCS platforms promotes greater rockfish abundance (e.g., by providing food or greater reproductive success) and thereby represents important habitat. The OCS platforms and adjacent receiving waters do not represent essential habitat for any threatened or endangered species or other areas of special biological significance.

The discharge permit requires testing for free oil, toxicity, oil content, oil and grease levels, solids, and chlorine concentrations in selected waste streams in order to ensure compliance with water quality limitations. Other requirements applying to all discharges are that there can be no discharge of visible foam and minimal use of dispersants, surfactants, and detergents. These limits are included to minimize potentials for impacts to organisms exposed to platform discharges.

Factor 5 - Existence of Special Aquatic Sites

As discussed for Factor 3, several areas of special biological importance occur near or overlap with the permit area. Although platform discharges will be widely dispersed, potentials for transport of platform wastes and accumulation at appreciable quantities in areas of special biological importance are considered negligible, particularly due to the large distances (at least three miles in most cases) from nearshore or coastal resources and extensive mixing and dilution of the discharges, as noted above. Previous studies of the Pacific OCS have demonstrated that platform wastes are not measurable at distances more than one or two kilometers from the discharge point. Consequently, platform discharges are not expected to cause significant changes to water or sediment quality within special status sites near the permit area.

Factor 6 - Potential Impacts on Human Health

The primary exposure route from platform discharges that would represent potential impacts to human health would be consumption of seafood containing discharge-related contaminants. However, potentials for direct ingestion, inhalation, or exposure through recreational activities to platform waste constituents are considered negligible.

Recent studies conducted in the Gulf of Mexico of fish and invertebrates exposed to produced water discharges concluded that these exposures did not cause significant bioaccumulation of contaminants in tissues of marine organisms. Consequently, potentials for impacts to human health through direct consumption of seafood also were considered insignificant. Furthermore, as noted above, mussels and other bivalves have been commercially harvested from OCS platforms for several years, and testing of mussel tissues demonstrated a general absence of contaminants in organisms harvested from the platforms. Thus, there is minimal potential through this exposure route for significant impacts to human health.

The permit prohibits the discharge of free oil, oil-based muds, and muds with diesel oil added. These prohibitions are based on the potential effects of the organic pollutants in these discharges to human and aquatic life, so no impacts would occur from these types of compounds.

Factor 7 - Recreational and Commercial Fisheries

Commercial and recreational fisheries in OCS waters of southern and central California are addressed in Section 6. Although the general permit supports productive fisheries, recreational and commercial fishing activities in the immediately vicinity of OCS platforms (i.e., discharge receiving waters) are generally limited, with the exception of commercial harvesting of bivalves from the platform structure (see Factor 6). Consequently, direct impacts from platform discharges to fisheries resources are considered negligible.

The conditions and limitations in the general permit are considered protective of water quality and the health of these fisheries. These permit conditions and limitations include no discharge of free oil, oil-based muds, or diesel oil, no discharge of produced sand, oil and grease limitations on produced water, discharged rate limitation around live-bottom (i.e., hard-bottom) areas, and limitations on the whole effluent toxicity of drilling fluids and produced water.

Factor 8 - Coastal Zone Management Plans

Section 7 provides an evaluation of the coastal zone management plan. The state will have an opportunity to review this evaluation along with the proposed permit to determine consistency with their plans. As detailed in Section 7, the permit meets the requirements of the plan implemented by the state and is considered by EPA to be in compliance with those plans.

Factor 9 - Other Factors Relating to Effects of the Discharge

Compliance with applicable conditions is addressed by the other factors.

Factor 10 - Marine Water Quality Criteria

Platform discharges are expected to comply with federal marine water quality criteria for pollutants. EPA has designated a zone of initial dilution extending 100 m from the discharge point. Waste constituents at a distance of 100 m from the discharge are expected to be below the corresponding water criteria values. Evaluations of compliance with these criteria values require information on the source concentrations and dilution rates, both of which are expected to vary considerably at individual platforms. Regardless, assessments can be performed using some assumptions concerning initial concentrations and dilution at the edge of the mixing zone.

An evaluation of compliance with water quality criteria for discharges of drill muds was performed by the Western States Petroleum Association and submitted as a comment on the draft version of the ODCE. The evaluation followed an approach used in ODCEs prepared for general permits by other EPA regions. The analysis of drill mud discharges was based on a representative drill mud with a density of 17.4 lb/gal, with constituent concentrations considered representative of muds used for OCS operations. Dilution rates were determined using the Offshore Operators Committee (OOC) dispersion model, which has been verified for use in Pacific OCS operations (O'Reilly et al., 1989). The model predicted dilution factors of 1,803 for solids and 1,721 for aqueous phases at a distance of 100 m from the discharge point (i.e., the edge of the designated mixing zone). Applying these dilution factors to constituent concentrations in the source drill muds yielded concentrations below the respective criteria for all components (metals and naphthalene) except beryllium (which exceeded the criterion by about 30%). However, it should be pointed out that the criterion for beryllium cited in the submittal is no longer being used by EPA, nor has EPA developed a replacement criterion. As such, EPA does not believe that the result would constitute an exceedance of Federal criteria.

Constituent data for produced water discharges within the Pacific OCS have been compiled by EPA. Analysis of these data indicated that reasonable potentials for exceeding water quality limits were associated with lead from one discharge source and benzo(a)pyrene from another. These two exceptions may correspond to sampling/analysis artifacts because a higher molecular weight compound such as benzo(a)pyrene is not expected to occur in measurable amounts in produced waters, and lead concentrations in produced waters typically are comparable to those in seawater. Benzo(a)pyrene is more characteristic of a combustion source such as soot particle than a petroleum source.

Based on these data and evaluations, platform discharges are expected to comply with applicable marine water quality criteria.

Conclusions

Based on consideration of the ten factors discussed above and detailed in this document, EPA Region 9 has determined that no unreasonable degradation of the marine environment will result from the discharges authorized under this permit, with all limitations, conditions, and monitoring requirements in effect.

After reviewing the available data, the Region has included a variety of technology-based, water quality-based, Best Management Practices, and Section 403-based requirements in the final permit to ensure compliance with this section of the Clean Water Act, under a no reasonable degradation determination as well as other relevant sections of the Act.

EPA has imposed a number of permit requirements on drilling fluids that eliminate or reduced potential impacts from authorized discharges. These include the following:

- Restrictions in barite use to low trace metal contaminant levels for drilling fluids;
- Prohibition of any discharges with oil-based muds and diesel oil as a mud additive;
- Limitations on oil and grease in produced water discharges;
- Enforcement of "no free oil" limits on numerous discharges from oil and gas extraction and production activities;
- Requirement to pass a static sheen test for detection of free oil before discharges occur; and
- Limitations on solids and chlorine for sanitary waste discharges.

1. INTRODUCTION

1.1 Background And Purpose of The Evaluation

Under Section 402 of the Clean Water Act, the Environmental Protection Agency is authorized to issue National Pollutant Discharge Elimination System (NPDES) permits to regulate the discharges of pollutant to waters of the U.S., the territorial sea, contiguous zone, and ocean. In February, 1982, the Regional Administrator of EPA Region IX issued a general NPDES permit (No. CA0110516) for effluent discharges at offshore oil and gas facilities in federal waters off southern California (47 FR 7312). This permit was issued for a two year period, to expire on December 31, 1983, at which time the permit limitations would be reevaluated and the permit reissued. On December 8, 1983, the permit was reissued for an additional 6 month period ending on June 30, 1984 (48 FR 55029). The permit was proposed for reissuance on August 22, 1985 (50 FR 34036) but was not finalized. A revised permit was proposed by Region IX on July 20, 2000 (65 FR 45063).

The general permit establishes effluent limitations, standards, prohibitions, and other conditions for OCS oil and gas facilities. The Regional Administrator is authorized (40 CFR 122.28) to issue general permits if the facilities meet the following guidelines:

1. Involve the same or substantially similar types of operations;
2. Discharge the same types of wastes;
3. Require the same effluent limitations or operating conditions;
4. Require the same or similar monitoring requirements; and
5. In the opinion of the Director, are more appropriately controlled under a general permit than under individual permits.

Use of the general permit streamlines the permitting process for facilities that are not anticipated to significantly affect the marine environment and allows flexibility appropriate for exploration activities that require mobility within permitted waters. Furthermore, the general permit allows EPA to provide a more effective area-wide monitoring program that permits better assessment of cumulative effects of multiple facilities within the permitted area.

The general permit covers discharges related to field exploration, drilling, production, well production, and well treatment. Region IX has identified 22 discharge types that may result from the aforementioned oil and gas activities. These discharges are as follows:

Discharge 001 - Drilling Fluids and Cuttings
Discharge 002 - Produced Water
Discharge 003 - Well Treatment, Completion, and Workover Fluids
Discharge 004 - Deck Drainage
Discharge 005 - Domestic and Sanitary Wastes
Discharge 006 - Blowout Preventer ("BOP") Fluid
Discharge 007 - Desalination Unit Wastes
Discharge 008 - Fire control system test water

Discharge 009 - Non-contact cooling water
Discharge 010 - Ballast and Storage Displacement Water
Discharge 011 - Bilge Water
Discharge 012 - Boiler Blowdown
Discharge 013 - Test Fluids
Discharge 014 - Diatomaceous Earth Filter Media
Discharge 015 - Bulk Transfer Material Overflow
Discharge 016 - Uncontaminated Freshwater
Discharge 017 - Waterflooding Discharges
Discharge 018 - Laboratory Wastes
Discharge 019 - Excess Cement Slurry
Discharge 020 - Drilling Muds, Cuttings and Cement at the Seafloor
Discharge 021 - Hydrotest Water
Discharge 022 - H_2S Gas Processing Wastewater

Under Sections 402 and 403 of the Clean Water Act, the Regional Administrator must determine that the NPDES permit is in compliance with EPA's Ocean Discharge Criteria guidelines (45 FR 65952). These guidelines set forth specific criteria for preventing unreasonable degradation of marine waters.

Ten factors are to be considered before the issuance of an NPDES permit (40CFR125.122):

- The quantities, composition and potential for bioaccumulation or persistence of the pollutants to be discharged;
- The potential transport of such pollutants by biological, physical, or chemical processes;
- The composition and vulnerability of the biological communities that may be exposed to such pollutants, including the presence of unique species or communities of species, the presence of species identified as endangered or threatened pursuant to the Endangered Species Act, or the presence of those species critical to the structure or function of the ecosystem, such as those important for the food chain;
- The importance of the receiving water area to the surrounding biological community, including the presence of spawning sites, nursery/forage and migratory pathways, or areas necessary for other functions or critical stages in the life cycle of an organism;
- The existence of special aquatic sites including, but not limited to marine sanctuaries and refuges, parks, national and historic monuments, national seashores, wilderness areas and coral reefs;
- The potential impacts on human health through direct and indirect pathways;
- Existing or potential recreational and commercial fishing, including finfishing and shellfishing;
- Any applicable requirements of an approved Coastal Zone Management plan;
- Such other factors relating to the effects of the discharge as may be appropriate;

and

- Marine water quality criteria developed pursuant to Section 304(a)(1).

If a determination of no unreasonable degradation is made, a permit may be issued. If the Regional Administrator has insufficient information on the proposed discharge or its potential effects, he/she may require additional information from the applicant. If a determination of unreasonable degradation or irreparable harm cannot be made, the Regional Administrator must "make a reasonable determination that the discharger operating under a permit with monitoring requirements and effluent limitations, will not cause permanent and significant harm to the environment" (47 FR 7316). If monitoring information indicates the discharge will produce unreasonable degradation, the activity must be halted or further permit limitations must be instituted.

1.2 Scope of the Evaluation

This document evaluates the potential impacts of the effluent discharges outlined above on 83 tracts from previous offshore lease sales off southern California (Figure 1.1). This is the area in which the discharges from the offshore oil and gas facilities would be authorized by the general permit. The tracts include 79 tracts currently considered active by the Minerals Management Service (MMS) and 4 tracts which were recently terminated by the MMS, but may be reinstated pending current litigation. These tracts are located in the Santa Maria Basin, the Santa Barbara Channel and the San Pedro Channel.

This evaluation includes analysis of a relatively large number of exploration, development, and production activities and operations. It cannot be determined exactly beforehand the actual numbers or which tracts will be explored and developed. However, based on current estimates by MMS (personal communication from Dave Panzer to EPA, Region 9) about 40-50 development wells will be drilled during the permit term from existing production platforms, and 5-6 exploratory wells will be drilled. Exploratory wells are drilled from exploratory drilling vessels (typically onsite for only a few months), and have similar discharges as production platforms with the exception of produced water. At the time the original permit was issued, 14 development/ production platforms (15-96 wells/platform) had been placed in the California OCS, and 8 others (36-72 wells/platform) have been installed since that time, for a total of 22 existing production platforms (California Coastal Commission, 1999). The California Coastal Commission estimates that these 22 platforms produce 120,000 barrels of crude oil/day and 210,000 thousand cubic feet (Mcf) of gas/day. Three additional platforms (Heather, Julius, and Independence) have been approved by the California Coastal Commission but not installed.

1.3 Organization of the Evaluation

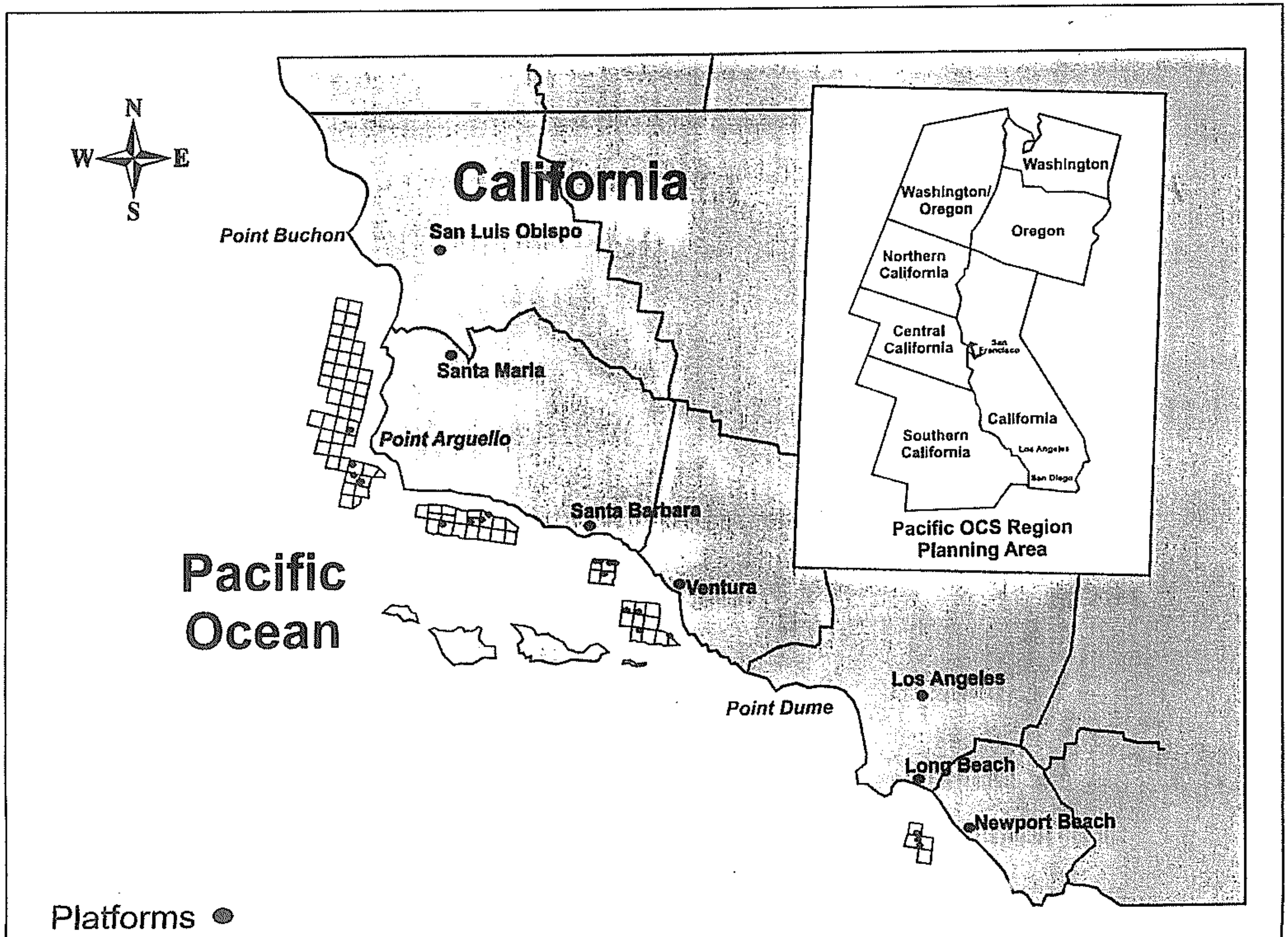
The 10 factors listed in the Ocean Discharge Criteria Evaluation guidelines (40CFRI25.122) have been considered and are discussed as follows:

- Composition and quantities of materials discharged (Section 2.0)
- Transport and persistence of materials discharged (Section 3.0)

- Toxicity and bioaccumulation of discharged materials, including human health effects (Section 4.0)
- Composition and vulnerability of biological communities, including unique or endangered species, important habitats, and species critical to the ecosystem structure and function, and importance of receiving water areas to these communities (Section 5.0)
- Commercial and recreational finfishing and shellfishing (Section 6.0)
- Coastal Zone Management consistency determination and marine water quality criteria (Section 7.0)

Table 1.1. Overview of Existing Oil and Gas Exploration and Production off the California Coast (California Coastal Commission, 1999).

Platform	Operator	Field	Year Installed	Number of Well Slots	Water Depth (ft)
Edith	Nuevo	Beta	1983	72	161
Ellen/Elly	Aera	Beta	1980	80	265/255
Eureka	Aera	Beta	1984	60	700
Gail	Venoco	Sockeye	1987	36	739
Gilda	Nuevo	Santa Clara	1981	96	205
Gina	Nuevo	Hueneme	1980	15	95
Grace	Venoco	Santa Clara	1979	48	318
Hogan	Pacific Operators	Offshore	1967	66	154
Houchin	Pacific Operators	Carpinteria Offshore	1968	60	163
Henry	Nuevo	Carpinteria Offshore	1979	24	173
Habitat	Nuevo	Pitas Point	1981	24	290
Hillhouse	Nuevo	Dos Cuadras	1969	60	190
A	Nuevo	Dos Cuadras	1968	57	188
B	Nuevo	Dos Cuadras	1968	63	190
C	Nuevo	Dos Cuadras	1977	60	192
Harmony	Exxon	Hondo	1989	60	1,198
Harvest	Chevron	Point Arguello	1985	50	675
Heritage	Exxon	Pescado	1989	60	1,075
Hondo	Exxon	Hondo	1976	28	842
Hermosa	Chevron	Point Arguello	1985	48	603
Hidalgo	Chevron	Point Arguello	1986	56	430
Irene	Torch	Point Perdenales	1985	72	242



Source: MMS Fiscal Year 2000-2001 Environmental Studies Plan

Figure 1.1. Study Area for Proposed NPDES Permit.

2. QUANTITIES AND COMPOSITION OF DISCHARGED MATERIALS

As discussed in Section 1.1, the reissued permit covers 22 discharges anticipated from exploration, development and production activities in the California OCS. This section describes the quantities and chemical compositions of the planned discharges. Drilling fluids (i.e., drill muds) and cuttings, and produced waters will be discharged in significant quantities, and these discharges could potentially impact marine biological communities. Other discharges are comparatively smaller in volume and/or have minor potentials for affecting water quality or impacting marine organisms.

2.1 Drill Muds and Cuttings

Drill muds are complex mixtures of clays, barite, and specialty additives used to remove cuttings from the drill hole, to maintain hydrostatic pressure within the hole, and to maintain fluid equilibrium between the hole and the formation. Cuttings are drilled formation solids that are carried by the drilling fluids from the hole to the surface, and then separated by solids control equipment and discharged (Menzie, 1982)

2.1.1 Quantity of Drilling Muds and Cuttings

Minerals Management Service (MMS, 1983) predicted volumes of drill muds and cuttings from the total 1984 Southern California Lease Offerings. These estimates are shown in Table 2.1. These wells were to be drilled over an unknown period of years. More recent estimates by MMS indicate that 40 to 50 development wells and 5 to 6 exploratory wells may be drilled during the 5-year permit period. Consequently, the volumes of drill mud and cuttings discharges are expected to be proportionately smaller that those shown in Table 2.1

The rates at which muds and cuttings are discharged are highly variable, and depend on the stage of drilling operations and well depth. During drilling, there is usually a fairly continuous low-level discharge (93-220 bbls/day) with an intermittent bulk discharge of higher volumes (500-2000 bbls/hr for 1-3 hrs) of drill muds. Bulk discharges occur when the mud type is changed, during cementing operations, when more diluent water is needed to adjust the solids concentration, and at the completion of drilling (Petrazuollo, 1983).

Table 2.1 Predicted Volumes of Effluents from Proposed Southern California Lease Offering, February 1984 (Total Lease Offering Development, MMS, 1983)

Sub-Area	Number Wells/ Platforms	Volume Cuttings (000s Barrells)	Volume Muds (000s Barrells)	Sewage (gal/day)
Santa Barbara Channel	460/10	810	1,164	38,000
Inner Basins	325/5	572	822	19,000
Outer Banks and Basins	505/12	899	1,278	45,600
Total	**1290/27**	**2,271**	**3,264**	**102,600**

Table 2.2 summarizes drilling activities at Platforms Harvest, Hildago, and Hermosa in Santa Maria basin during 1986 to 1994 (Hyland et al., 1994; Phillips et al., 1998). Estimates of drill mud discharges listed in Table 2.1 equate to 2,530 m^3/well (6.2 bbl/m^3), which is about 2.5 times higher than actual discharge volumes (940 m^3) from the three Santa Maria Basin platforms. Based on average drill mud discharges from these platforms in Santa Maria Basin, and the predicted numbers of wells drilled during the five-year permit period, discharge volumes for drill muds and cuttings could represent 52,700 m^3 and 9,800 m^3, respectively. These discharges would occur at the drilling sites, which are expected to be primarily in the Santa Barbara Channel and Santa Maria Basin. Consequently, these discharges would not be concentrated in one geographic location.

Table 2.2 Summary of Drilling Activities off Point Arguello, California from 1983 to 1994 (Hyland et al., 1994; Phillips et al., 1998)

Platform	Drilling Period	Number of Wells	Mud Discharge (m^3)	Cutting Discharge (m^3)
Harvest	Nov 86 - May 88	19	16,340	0
Hermosa	Jan 87 - Sept 88 Sept 93 - Nov 93	13 1	16,373 822	3,114 136
Hidalgo	Nov 87 - Jan 89 Nov 93 - May 94	7 4	7,963 3,850	2,294 739
Irene	Apr 86 - Oct 89	18	12,967	4,585

2.1.2 Composition of Drill-Muds and Cuttings

Currently, there are eight generic water-based drill muds which have been approved for use by EPA (Table 2.3). Discharges of oil-based drilling fluids into marine waters is prohibited by EPA. In general, water-based drill muds consist of a variety of component additives in fresh or salt water. A typical drilling fluid consists of viscosifiers (gels) such as bentonite, weighting agents (e.g., barium sulfate), thinners, fluid loss control agents, and caustic soda for pH control. Other additives are used as required by the down-hole conditions encountered. Thus, the specific composition of the drill muds is likely to change depending on the drilling conditions and well depth.

Table 2.3 Approved Drilling Mud Types (Jones and Stokes, 1983)

Components	Maximum Allowable Concentration (lb/barrel)
Seawater/Freshwater/Potassium/ Polymer Mud	
KCL	50
Starch	12
Cellulose polymer	5
XC polymer	2
Drilled solids	100
Caustic	3
Barite	450
Seawater or freshwater	As Needed
Seawater/Lignosulfonate	
Attapulgite or bentonite	50
Lignosulfonate	15
Lignite	10
Caustic	5
Barite	450
Drilled solids	100
Soda ash/sodium bicarbonate	2
Cellulose polymer	5
Seawater	As Needed
Lime	
Lime	20
Bentonite	50
Lignosulfonate	15
Lignite	10
Caustic	5
Barite	180
Drilled solids	100
Soda ash/sodium bicarbonate	2
Seawater or freshwater	As Needed
Nondispersed	
Bentonite	50
Acrylic polymer	2
Barite	180
Drilled solids	70
Seawater or freshwater	As Needed
Spud	
Lime	1
Attapulgite or bentonite	50
Caustic	2
Barite	50
Soda ash/sodium bicarbonate	2
Seawater	As Needed
Seawater/Freshwater Gel	
Lime	2
Attapulgite or bentonite	50
Caustic	3
Barite	50
Drilled solids	100
Soda ash/sodium bicarbonate	2
Cellulose polymer	2
Seawater or freshwater	As Needed
Lightly Treated Lignosulfonate Freshwater/Seawater	
Lime	2
Bentonite	50
Lignosulfonate	6
Lignite	4
Caustic	3
Barite	180
Soda ash/sodium bicarbonate	2
Drilled solids	100
Cellulose polymer	2
Seawater to freshwater ratio	1:1-approx.
Lignosulfonate Freshwater	
Lime	2
Bentonite	50
Lignosulfonate	15
Lignite	10
Caustic	5
Barite	450
Drilled solids	100
Cellulose polymer	2
Soda ash/sodium bicarbonate	2
Freshwater	As Needed

Drill muds may contain a number of trace metals and petroleum hydrocarbons at concentrations that are higher than corresponding levels in marine sediments. The presence of certain metals and hydrocarbons represents a potential concern for water quality impacts, acute and chronic toxicity, and/or bioaccumulation of chemical contaminants in marine organisms. Barium typically is the most abundant metal in drill muds using barite (barium sulfate) as a principle additive. Barium concentrations in used drill muds may reach levels that are two orders of magnitude higher than average crustal abundances (i.e., natural concentration in source rocks).

The trace metals; lead, zinc, mercury, arsenic, cadmium, and chromium may be present in drill muds due to impurities in barite or picked up by the muds from pipe dope. Concentrations of metals in generic drill muds as compared to the earth's crust are shown in Table 2.4. It should be noted that the ranges presented here are considered typical; trace metal concentrations at specific sites may vary by two to three times from those shown here.

Table 2.4 Comparison of the Range of Trace Metal Concentrations in Typical Drilling Muds and Average Earth's Continental Crust (Crust Values from Ronov and Yaroshevsky, 1972; Drill Muds Data from Ayers et al., 1983)

Metal	Drilling Muds (ppm)	Continental Crust (ppm)
Arsenic	1-3	1.8
Barium	2,800-141,000	425
Cadmium	1	0.15
Chromium	2-265	120
Copper	2-26	60
Lead	1-24	14
Mercury	1	0.085
Nickel	1-8	84
Vanadium	0-35	120
Zinc	12-18	70

Steinhauer et al. (1994) conducted extensive chemical characterization of drill muds and cuttings from platforms, Hidalgo, Hermosa, and Harvest, off the California coast at Point Arguello. Drill muds used at these platforms contained approximately 40% by weight of barite, 24% bentonite, and less than 10% each of potassium chloride and carbonate; other additives comprised approximately 25% of the total dry weight. Mud and cuttings samples from surface, mid-well, and bottom depths of five wells were analyzed for metals and hydrocarbons. Table 2.5 shows mean concentrations of metals and hydrocarbons in muds and cuttings from surface, mid-well, and bottom depths. Average barium concentrations in the drill muds were approximately 300 percent higher than the background sediment concentrations. With the exception of zinc, other metals in the drill muds were generally similar (e.g., within a factor of two) to the corresponding background sediment concentrations. During this study, barium was the only chemical component of the drill mud that exhibited a clear signal of discharge-related changes to suspended or bottom sediments (Hyland et al., 1994).

Table 2.5 Composite Average Concentrations of Metals and Hydrocarbons in Drill Mud and Cuttings from Surface, Mid-well, and Bottom Depths of Five Wells at Platform Hidalgo and Corresponding Background Concentrations (Steinhauer et al., 1994; Hyland et al., 1994)

Chemical (ug/g)	Drill Mud	Cuttings	Background
Silver	0.28	0.57	0.14
Arsenic	6.34	10	6.5
Barium	107,782	5,200	703
Cadmium	1.2	2.29	0.72
Chromium	85	152	99
Copper	30	48	21
Mercury	0.13	0.1	0.075
Nickel	41	67	48
Lead	19	1,926	14
Vanadium	71	105	81
Zinc	290	1,346	71
Total Hydrocarbons	390	407	80
Sum PAHs	25	45	0.06
Naphthalenes	18	35	
Fluorenes	1.6	2.8	
Phenanthrenes	2.8	3.6	
Dibenzothiophenes	1.9	2.8	

Table 2.5 also lists concentrations of total hydrocarbons, summed polycyclic aromatic hydrocarbons (PAHs), and specific PAH compounds (parent plus alkylated homologs) in drill muds from platforms Harvest, Hidalgo, and Hermosa. Similar to the trace metal concentrations, petroleum hydrocarbon content of drill muds vary considerably and reflect the amount of the formation product encountered during drilling. Average concentrations of one PAH component, naphthalenes, were elvated in drill muds relative to those in background sediments. However, study results did not observe changes in naphthalene concentrations in suspended or bottom sediments related to drill mud discharges. The absence of these expected changes may be due to the solubility of naphthalenes and their loss due to dissolution and/or microbial degradation during settling of drill mud particles.

Trace metals and hydrocarbons in drill muds occur in both particulate and dissolved phases, although only a small fraction of the bulk concentration typically is associated with the dissolved fraction (EPA, 1985). The association of metals and hydrocarbons with drill mud particles has important implications to the subsequent transport and fate of these materials (Boehm, 1987).

The chemical composition of cuttings discharges is expected to reflect the composition of the source rocks, as well as the amount and characteristics of any formation hydrocarbons and/or drill muds adhering to the cuttings that are not removed during the solids screening process. Trace metal and hydrocarbon concentrations in cuttings from Platform Hermosa are listed in

Table 2.5. Concentrations of several metals, including lead and zinc which may have been from pipe thread compounds, were considerably higher, while concentrations of barium were appreciably lower, than those in drill muds (Steinhauer et al., 1994). Concentrations of all metals except chromium and mercury were also higher than respective concentration in surface sediments.

2.2 Produced Water

The water associated with oil and gas resevoirs is commonly known as "formation water," "produced water," or "oilfield brine." These terms have been used interchangeably throughout the literature. For the purpose of this report, the term "produced water" will be used and will denote the final effluent entering the receiving marine waters with no distinction made as to the level of treatment at the production platform. Produced water resulting from separation from the oil and gas mixture often contains measurable amounts of hydrocarbons and other organic compounds, dissolved salts, and metals.

Information for produced waters of coastal California has been summarized in Neff (1997).

2.2.1 Quantities of Produced Water

Current estimates of produced water discharge to the waters off California (Neff, 1997), vary widely. The Minerals Management Service estimated that 8.82 million gallons of produced water were discharged between 1987 and 1991, or 1.79 million gallons per year (MMS, 1995). The Western States Petroleum Association provided information (Neff, 1997) to indicate that discharge rates for 14 platforms range from 42,000 to 840,000 gal/day, and the total average discharge to waters in the Santa Barbara Channel alone is 4.28 million gal/day. Produced water discharges from Platforms Harvest, Hermosa, and Hidalgo in the Santa Maria Basin were approximately 211,000 gal/day, 400,000 gal/day, and 250,000 gal/day, respectively, starting in 1993 (SAIC and MEC, 1995).

These volumes are comparable with those reported from drilling operations worldwide, as follows (Neff, 1997):

8.15 mgd in the Norwegian sector of the North Sea;
5.01 to 25.6 mgd in the West Java Sea;
27.7 mgd in Gulf of Mexico from 1987 to 1991;
3.95 mgd in Cook Inlet, AK.

2.2.2 Composition

The predominant chemicals that are naturally-occurring in produced waters include inorganic salts similar to those in seawater, metals and metalloids, and numerous forms of organic chemicals. Table 2.6 summarizes the extreme ranges of concentrations of these chemicals in produced water expected on a world-wide basis. It should be noted that these concentration ranges are very large and that the higher values are extremely rare. Concentrations of these compounds in northwest Gulf of Mexico produced waters are more typical and are in the lower portion of these extreme ranges. Table 2.7 shows the concentrations of selected metal and organic compounds in coastal California and Gulf of Mexico produced waters.

Table 2.6 Concentration Ranges of Several Classes of Naturally-occurring Organic Compounds and Metals in Produced Water Worldwide (Neff, 1997)

Compound Class	Concentration Range (ug/L)
Total Organic Carbon	<100-2,100,000
Total Saturated Hydrocarbons	17,000-30,000
Total Benzene, Toluene, Ethylbenzene, Xylenes (BTEX)	68-578,000
Total Polycyclic Aromatic Hydrocarbons (PAHs)	80-3,000
Steranes/Triterpanes	140-175
Ketones	1,000-2,000
Phenols	600-21,500
Organic Acids	<1-10,000,000
Sulfate	<1,000-8,000,000
Arsenic	0.004-320
Barium	<1-2,000,000
Cadmium	0.0005-490
Chromium	<0.001-390
Copper	<0.001-55,000
Lead	<0.001-18,000
Mercury	<0.001-33.0
Nickel	<0.01-1,674
Zinc	0.005-150,000

Table 2.7 Ranges in Mean Concentrations of Selected Organic and Inorganic Chemicals in Produced Water from 12 Platforms in the Southern California Bight and Northwest Gulf of Mexico (Neff, 1997)

Chemical (ug/L)	California	Gulf of Mexico
Arsenic	ND-87	0.5-31
Cadmium	ND-15	<0.05-3.3
Chromium	ND-15	<0.1-0.2
Copper	ND-15	<0.2-2.1
Lead	ND-50	<0.1-28
Mercury	ND-0.65	<0.01-0.2
Nickel	ND-150	<1.0-7.0
Selenium	ND-29	NA
Silver	ND-93	NA
Zinc	ND-740	0.01-1,500
Phenols	ND-1,017	320-610
2,4-Dimethylphenol	ND-21	NA
Benzene*	ND-745	230-2,700
Toluene*	ND-268	340-1,600
Ethybenzene*	ND-29	28-110
Naphthalene*	ND-25	20-90
Benzo(a)pyrene*	ND	<0.001-0.09

ND - Not detected; NA - Not analyzed; * - one platform

For the new general permit, EPA reviewed the monitoring data for produced water which has been submitted by California offshore operators over roughly the last ten years to assess the reasonable potential of the discharges to cause or contribute to exceedances of Federal marine water quality criteria (63 FR 68354 and EPA's Quality Criteria for Water (the "Gold Book")). The data were analyzed in accordance with the statistical procedure in EPA's Technical Support Document for Water Quality-Based Toxics Control (EPA/505/2-90-001). Based on this review, reasonable potential to exceed the applicable criteria was estimated to occur in only two instances: for lead at Platform Hogan and for benzo(a) pyrene at Platform Gail. Effluent limitations will be proposed in the new general permit for these parameters for these platforms. The new general permit will also require additional monitoring for 26 parameters of concern in produced water (ammonia, arsenic, cadmium, copper, cyanide, lead, manganese, mercury, nickel, selenium, silver, zinc, benzene, benzo (a) anthracene, benzo (a) pyrene, chrysene, benzo (k) fluoranthene, benzo (b) fluoranthene, dibenzo (a,h) anthracene, hexavalent chromium, phenolic compounds, toluene, ethylbenzene, naphthalene, 2,4-dimethylphenol, and sulfides) and also whole effluent toxicity. At the present time, EPA does not have complete data for all of these parameters in produced water discharges for California platforms. After data are collected for ten samples for all of the above parameters (in about 2 ½ years into the term of the new permit), the data will analyzed for the reasonable potential to exceed marine water quality criteria. Additional effluent limitations may be established in the permit based on this review.

Minor Discharges

The volume of treated sewage generated per person per day is approximately 100 gallons (USDI, 1983). This would result in a total discharge per platform of 7,600 to 11,400 gal/day.

Desalinization brines are a byproduct of freshwater generation. These discharges are generally slightly more saline (15-20%) than surface and warmer than ambient sea water. Up to 200,000 gal/day may be discharged per platform, although volumes are highly variable.

Cooling water discharges, consisting of seawater used primarily to cool diesel engines during drilling, are another minor discharge source from OCS platforms. Discharge volumes may approximate 1,000 cubic meters per day. Water temperatures may exceed those of the receiving waters by up to 12 °C, but salinities of the cooling water discharges are not expected to change. Mixing and dilution of cooling water discharges are expected to reduce the temperature differences to an estimated 0.1 °C within 100 m of the discharge point.

3. TRANSPORT AND FATE OF DISCHARGES

Transport and fate of drill muds and cuttings and produced waters are controlled by several factors, including the physical and chemical characteristics of the discharged materials. Physical factors are that affect transport and dispersion of discharges may include water stratification and current regime. These conditions are, in turn affected by regional and localized meteorological processes. Chemical and biological processes also may play important roles in the fate of discharges. These factors are described below, followed by a preliminary analysis of the transport of discharged-related materials.

Oceanographic conditions off central California (Santa Maria Basin) and the Southern California Bight are predominantly controlled by the California Current System. However, there are significant differences in coastal orientation, coastal and submarine topography, wind and wave conditions, and water properties (temperature, salinity) among other factors which influence the local and/or regional circulatory patterns. An important difference between central California and Southern California Bight is the change in coastal orientation and submarine topography in the vicinity of Point Conception. The north-south trend of the central and northern California coast changes abruptly at Point Conception to the east-west trend of the Santa Barbara Channel and then gradually changes to a northwest-southeast trend for the remainder of the Southern California Bight. The submarine topography changes from a somewhat simple offshore gradation incised by submarine canyons to a complex topography of basins and ridges of the Southern California Bight. In addition, the area near and north of Point Conception is subject to strong and relatively persistent upwelling with associated low surface temperatures and elevated nutrient levels. In the Bight, upwelling is less persistent and surface temperatures tend to be warmer. The majority of the discussion centers on the general characteristics of the Southern California Bight. When available, supplemental information is provided on specific permit areas of the Santa Maria Basin and Santa Barbara Channel.

3.1 Climate and Meteorology

The climate of the Southern California Bight is of the Mediterranean coastal type, characterized by warm, dry summers and short, wet, mild winters (Daily et al., 1993). The abrupt change in coastal orientation produces a marked change in climate. The climate of central California is characterized by cool, damp, and foggy summers or warm, dry summers and wet, mild winters depending on the location.

A subtropical high pressure system produces weak southerly and onshore wind flow within the Southern California Bight. In general, wind speeds are on the order of 10 km/hr, and are relatively lower near the coast than areas immediately offshore (Daily et al., 1993). Winds north of Point Conception typically are stronger and less variable than those within the Bight. Differential heating of the land and sea results in wind patterns that include a sea breeze during the day and a land breeze during the evening. The evening breeze may extend seaward beyond 20 km. During winter, when the differences in temperature between land and sea are small, the sea breeze is weaker.

The average wind field off southern California is illustrated in Figure 3.1. Average wind speeds are 8–15 kts over the Santa Barbara Channel. 6–12 kts over the inner basins including the San Pedro area, and 8–14 kts over the outer banks and basins. The predominant wind direction offshore is from the northwest.

In the Southern California Bight, two local wind conditions. Catalina Eddy and Santa Ana, exist which can cause significant growth of local wind waves (Figure 3.2). The Catalina Eddy and Santa Ana winds are caused by local oceanographic and meteorological conditions. The Catalina Eddy is a cyclonic vortex, formed by northwest-north winds flowing around the coastal headlands and Santa Ynez Mountain Range near Point Conception. The northeast to east Santa Ana winds occur primarily in fall and winter. They originate from the interior and are warm, dry winds which flow down the mountain passes and out over the coast. The winds can extend 300 km offshore and attain speeds of >50 kts.

Air temperatures of the coastal and offshore areas are moderate with relatively little diurnal and seasonal ranges--the diurnal range is only a few degrees less than the mean annual range. Generally, temperatures offshore and along the coast tend to increase southward. The mean temperatures range from about 11° – 15°C (52° – 59°F) in January and 17° – 21°C (62° – 70°F) in July. Extremes in temperatures are uncommon, though temperatures of 38°C (100°F) have been recorded. Freezing temperatures occur rarely along the coast and very rarely offshore. Temperature inversions can occur in the coastal areas of central and southern California.

Precipitation tends to decrease from north to south and further offshore for central and southern California. However, elevation, topography (land and marine-islands), and coastal orientation can affect precipitation locally and regionally. Compared to southern California, central California is less protected from winter frontal systems and receives more precipitation. Annual precipitation in the area typically ranges from about 25 to 38 cm (Daily et al., 1993). Most of the precipitation for both areas occurs during the winter, reflecting the regional meteorological conditions (primarily weakening and migration of the Pacific High). Severe flooding can occur during the winter.

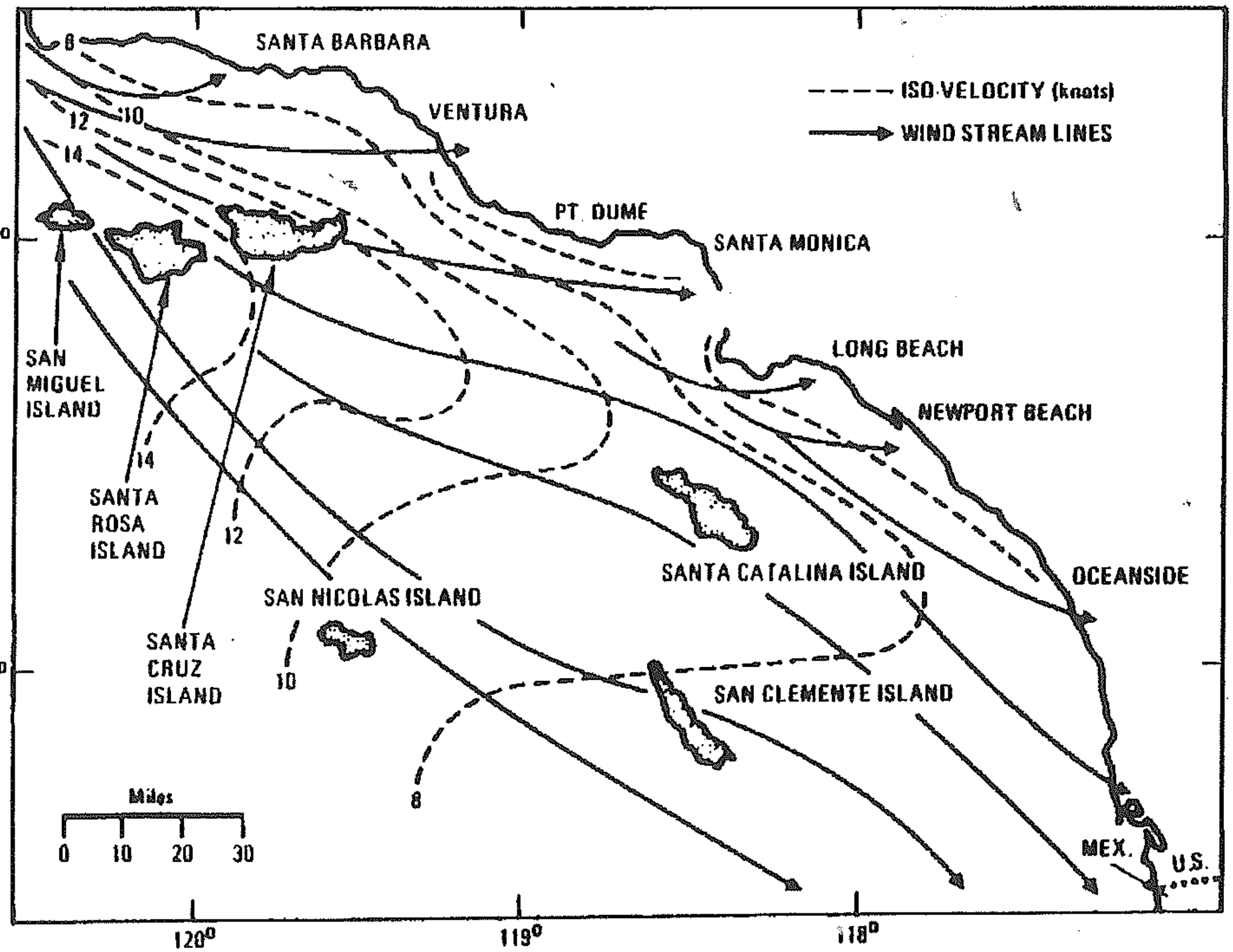


Figure 3.1

AVERAGE WIND FIELD OFFSHORE SOUTHERN CALIFORNIA (from Allan Hancock Fndtn., 1965).

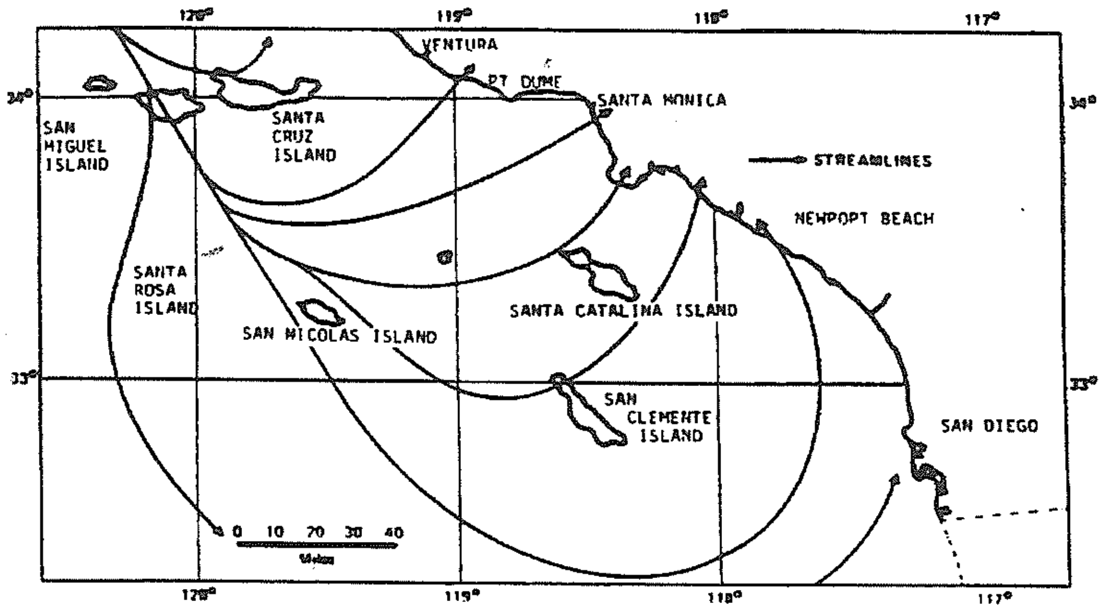


Figure 3.2a

TYPICAL WIND FIELD PATTERN DURING CATALINA EDDY CONDITION OFFSHORE SOUTHERN CALIFORNIA (The Aerospace Corporation, 1977, after Graham, 1950)

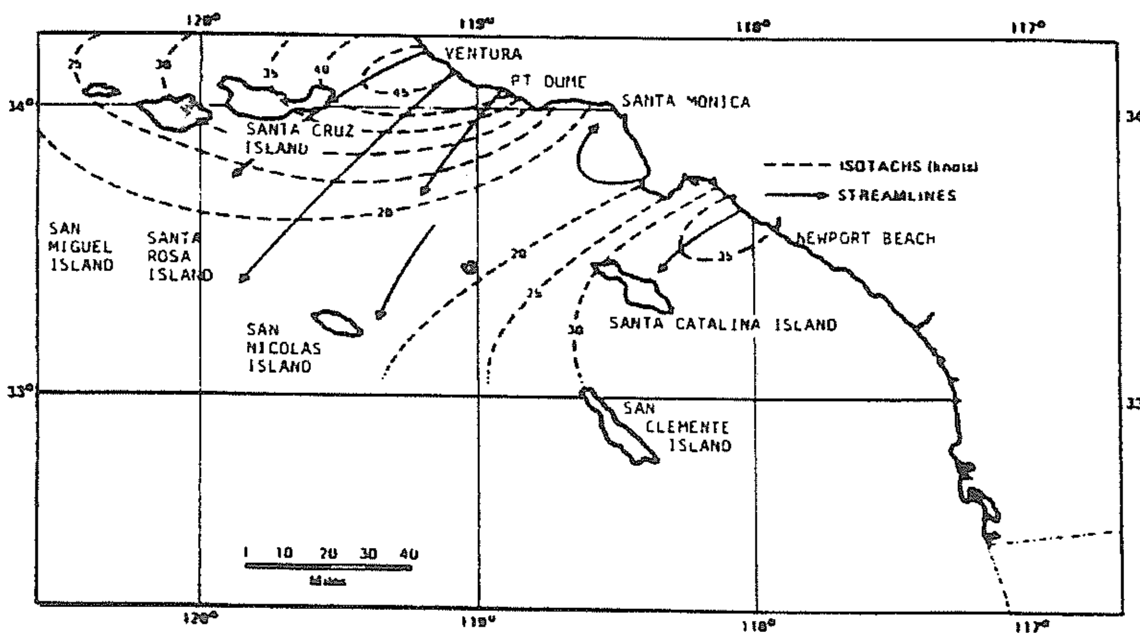


Figure 3.2b

SANTA ANA WIND CONDITION OFFSHORE SOUTHERN CALIFORNIA (from Strange, 1973)

3.2 Bathymetry and Submarine Physiography-Topography

The submarine physiography of the permit area is divided into three physiographic provinces. The provinces include: (1) the north-south trending Coast Range province of which the Santa Maria Basin is a part; (2) the east-west trending Traverse Range of which the Santa Barbara Channel and Basin are a part; (3) the northwest-southeast trending Peninsular Range of which the offshore inner and outer basins, banks, and ridges are a part (Figure 3.3). The latter two are components of the Southern California Bight and are separated by the Channel Islands. Refer to Richmond et al. (1981) for a physiographic summary of all the lease areas of the Bight.

Santa Barbara Channel is the seaward extension of the east-west trending Traverse Range province (Figure 3.3). The two physiographic features of the Channel are the Santa Barbara Basin and the Channel Island Platform. The Channel is about 130 km in length, 40 km in average width and has a maximum water depth of 625 m (Central Deep). It is bounded on the north and south by the mainland and northern Channel Islands, respectively. Water enters and exits the Channel via the west and southeast borders. The water depth to the sill between Point Conception and San Miguel Island is 475 m, while between Anacapa Island and Oxnard it is 230 m. Although the Channel is oriented east-west, the topographic trend of the Santa Barbara Basin is west-northwest and therefore controls circulation in the Channel.

On the mainland, the continental shelf generally has a gentle slope and extends to 100 m depth (Figure 3.3). The width varies from 4–5 km from Point Conception to Santa Barbara (Mainland Shelf), then slowly broadens eastward to 20 km off Oxnard (Oxnard Shelf). The continental slope is fairly steep between 100-250 m depth, then becomes broader with a gentler slope towards the Central Basin. The east end of the Oxnard Shelf is incised by several submarine canyons, the largest being Hueneme and Mugu Canyons which extend to Santa Monica Basin. Other topographic features on or near the Oxnard Shelf include the Dos Cuadros Ridge and 12 Mile Reef. On the Channel Island Platform, the shelf varies in width from 2–4 km and in depth from 90–130 m. Similar to the mainland, the slope is steep from 130–250 m depth, then becomes broader and gentler sloping towards the Central Basin. Water depths of the three passes between the Channel Islands are less than 50 m.

The remainder of the Southern California Bight is the seaward extension of the northwest-southeast trending Peninsula Range province. The province is characterized by a series of north-northwest to southeast trending ridges and basins with islands representative of peaks of some ridges. The province is divided into the inner basins and ridges and the outer basins and banks. In the permit area, the San Pedro lease tracts lie within the inner basins and ridges.

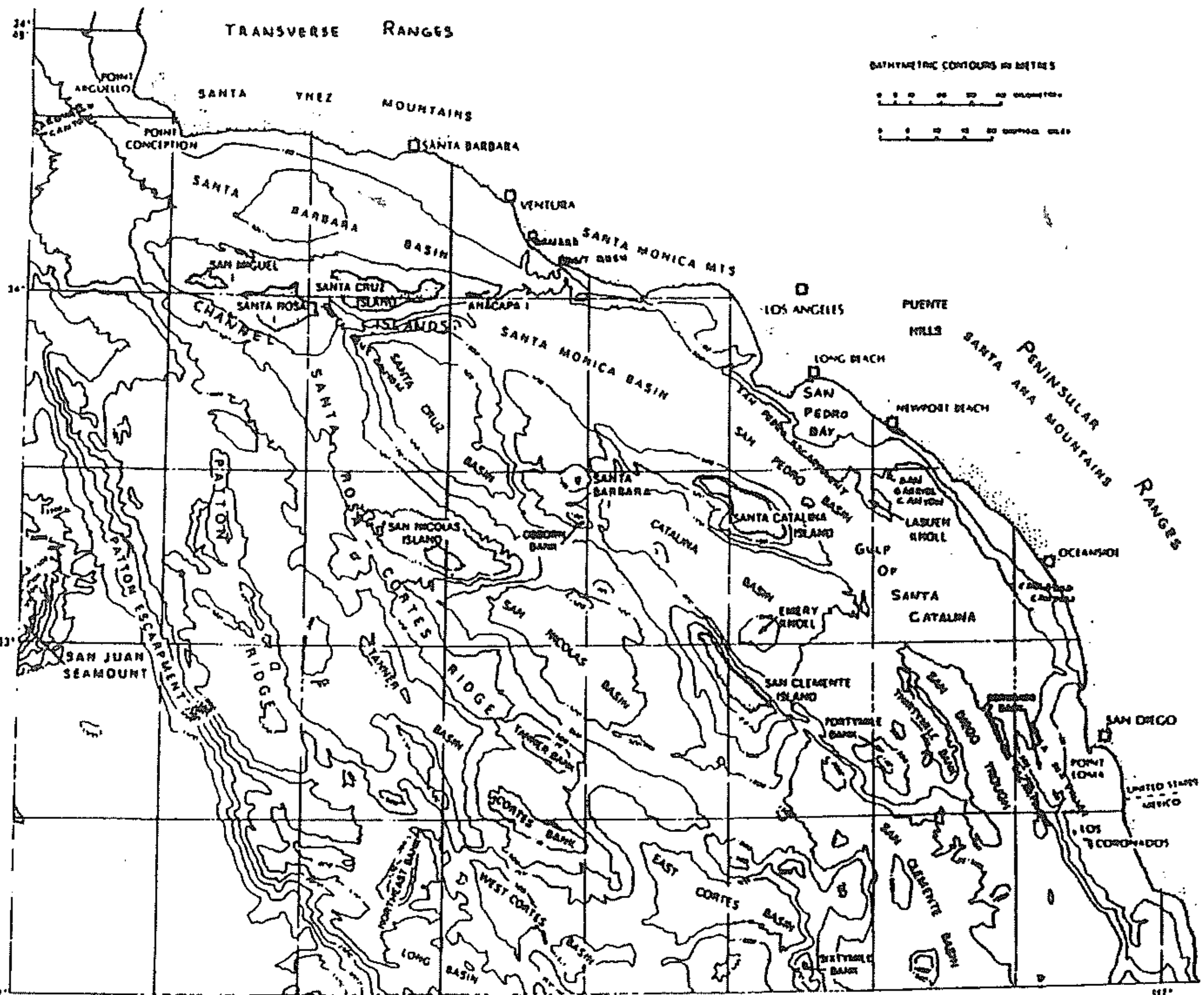


Figure 3.3

TOPOGRAPHIC MAP OF THE SOUTHERN CALIFORNIA CONTINENTAL BORDERLAND
(modified after Vedder and others, 1974; from Richmond et al., 1982)

Briefly, basins are found in water depths from 400–2,000 m for the inner basins to >3,000 m for the outer basins (Figure 3.3). The basins are typically 50–100 km long and 20–50 km wide. The inner ridges tend to be flat-topped and generally extend upwards to water depths less than 150 m and include the continental shelves. Water exchange between basins occurs over the sills—the lower parts of the- ridges and banks. Sills range in water depth from 250–2,000 m (Gorsline and Kolpack, 1981).

The northwest-southeast trending Santa Rosa-Cortes Ridge has an important role in the circulatory patterns of the southern California Eddy. The seven major geomorphic units of the area are the island-shelf margin (of the northern Channel Island Platform), the wave-cut ridge top, areas of rocky outcrops, the ridge escarpment, intermediate basins, the ridge flanks, and basement outcrops (Greene et al., 1975). The flat ridge top and coarseness of the sediments are indicative of possibly strong bottom currents and strong bottom surges.

The San Pedro lease area lies on the San Pedro continental shelf/slope and basin (Figure 3.3). The maximum water depth of the lease area is about 500 m. The continental shelf and slope lie within and seaward of the coastal indentation (San Pedro Bay) just south of the Palos Verdes Peninsula. The coastline tends to curve inwards while the bathymetric contours curve outwards at the shelf break. The shelf is broad in the central area and narrows seaward off Palos Verdes Peninsula and southeast off Newport. Between 90–500 m depth, the slope is fairly steep, particularly between 90–250 m, before gradually decreasing towards San Pedro Basin. Several submarine canyons incise the shelf/slope, some extending to San Pedro Basin. The major canyons are the San Pedro Canyon or Sea Valley on the west, the San Gabriel Canyon on the south and the Newport Canyon on the southeast. The latter two have several submarine tributaries in the upper limits.

The Santa Maria Basin is about 40 km long, 230 km wide and generally parallels the coast from Point Sur to Point Conception. The basin is bounded on the south by the Arguello Plateau-Santa Barbara Basin, on the southwest-west by the Santa Lucia Banks and continental slope and on the northwest-north by Point Sur—Sur Submarine Canyon. Unlike the Southern California Bight, the offshore bathymetry is more regular and generally free of shoal areas, islands, and other protective topographic features.

Physiographically, Santa Maria Basin can be divided into a north and south section near Cape San Martin. The permit area is within the southern section and is described in more detail. The southern section, consisting of the continental shelf and Arguello Plateau of the upper continental slope, is wide, has a gentle seafloor slope, and is incised by only a few submarine canyons. The Arguello Plateau is about 50 km wide and is cut by the gently sloping Arguello Submarine Canyon, the only major canyon on the plateau. Three small submarine canyon tributaries of the shelf enter the canyon. Water depths vary from 500–650 m in the deeper parts of the southern basin and up to 400 m on the Santa Lucia Banks. The basin grades on to the continental slope of the northern section. The northern section of the Santa Maria ocean basin is characterized by a narrow continental shelf (2–5 km) and a definite shelf /slope break at 180 - 200 m. The continental slope is steep and has a complex topography with several submarine canyons. The major canyons from south to north are the Lucia, Parrington, and Sur submarine canyons.

3.3 Tides and Waves

The tidal range along the west coast is typically 1–2 m (NOS, 1982), and the generally narrow shelf and fairly straight coastline does not amplify the tide significantly. The tide in the permit area is a mixed semi-diurnal type with two high and two low tides of unequal magnitude daily. Bathymetry, and local and regional oceanographic and meteorological conditions can significantly alter the tidal range and tidal velocity at different locations along the coast. For the Santa Maria Basin, the mean tidal range is about 1.1 m with an average tidal current of about 25 cm/s (NOS, 1978; NOAA, 1980).

The tidal range for the Santa Barbara Channel is 1.5–2 m. The tide enters the Channel via the southeast end, moves northward up the coast, and exits at the west end (Emery, 1960; Hendershott, 1981). The difference in time of peak tide between the east and west ends is typically one hour with the tide proceeding northward up the coast. Expected tidal-induced currents are approximately 10 cm/s (mean). However, constrictions between islands (passes) and regions near promontories and peninsulas (e.g., Point Conception) can be expected to accelerate tidal currents. These accelerated tidal currents would be added directly onto the mean currents discussed above.

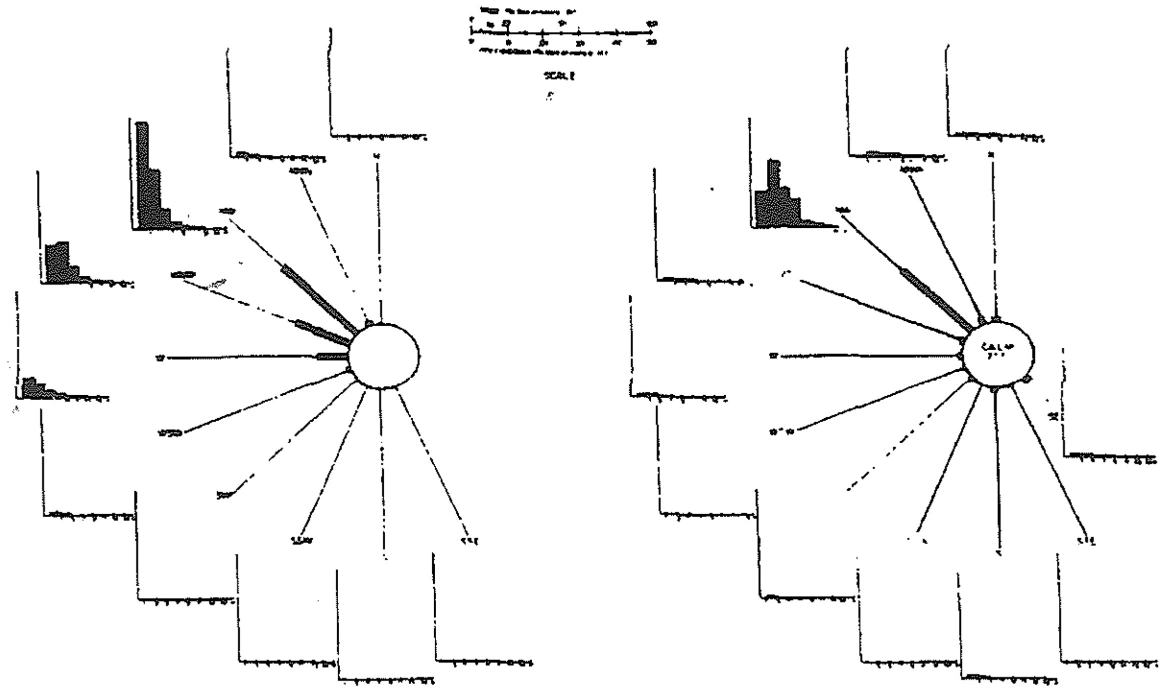
Surface gravity waves can exert strong forces on structures such as oil platforms, as well as contribute to currents and mixing in surface waters (Guza and O'Reilly, 1991). Seas (wind waves) and swells are the dominant wave types involved with the horizontal and vertical mixing and transportation of water and its constituents. Seas are locally generated by local storms and tend to produce choppy seas. Swells, characterized by long periods and wavelengths, are generated far out at sea and have traveled long distances before impinging on the continents. Swells generated by winter storms tend to be more damaging.

Ocean waves off southern California can be categorized as follows: (1) northern hemisphere swell generated in areas to the north; (2) southern hemisphere swell generated south of the equator; and (3) locally generated seas (Guza and O'Reilly, 1991). The wave climate off the central and southern California coast is governed by the regional and local meteorological and oceanographic conditions, as well as the sheltering effect of the Channel Islands for waves in the Southern California Bight (Hickey, 1993). Regional conditions control the seasonal and annual variations in wind and wave set-up while local conditions control the daily variations. Submarine topography and coastal orientation control the energetics of regionally and locally generated waves (seas and swells). Submarine topography controls wave refraction which is responsible for the concentration or dissipation of wave energy. Coastal orientation determines the degree of exposure (openness) of the coast to wave attack.

A brief summary of the wave climate for Santa Barbara Channel is given below. Local storms from the southeast generate wind waves (seas) over a fetch of 145 km. These local waves have significant wave heights that range from 2.4–4.8 m and generally have short periods (8–9 s). Swells enter Santa Barbara Channel from the southwest-west between San Miguel Island and

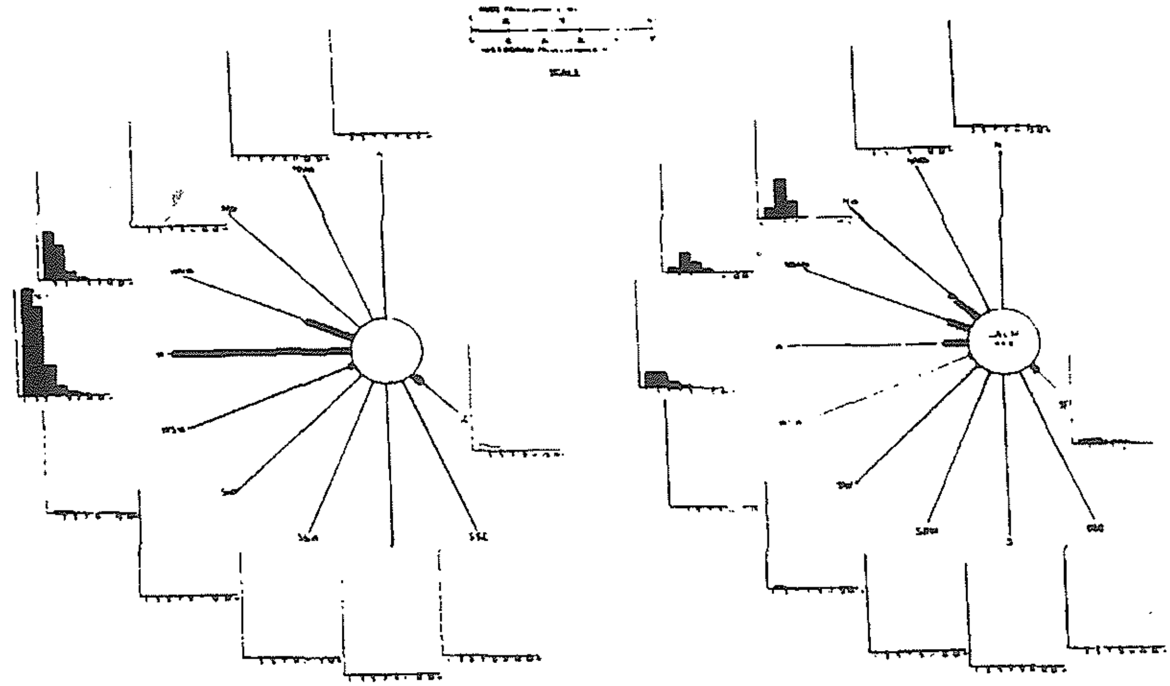
Point Conception and the Channel Island wave windows. These swells have significant wave heights and periods that range from 0.3 - 5.0 m and 8 - 16 s, with averages of 0.9 m and 12 s, respectively (Gable, 1981). From the hindcast study by National Marine Consultants (1960), the highest waves were swells with periods of 14 - 16 s and occurred in April (Figure 3.4). The predominant direction of the swells were west-northwest, west, west-southwest, and southeast, with southeast swells generally having shorter periods. Wind waves had significant wave heights generally lower than swells and had a maximum period of 12 s. The highest wind waves were from the southeast.

Wave energy is slightly higher for the central California coastal and offshore region than the Southern California Bight because of the coastal orientation and submarine topography. Waves approach the north-south trending central California coast from the north-west-south directions. The high wave energy of the central California coastal area is also reflected in the ruggedness of the coastal area with rock outcrops and stacks, and in the coarseness of the sediments (boulders, gravel, coarse sand). In the Southern California Bight, the complex topography of the basins and ridges and the presence of the offshore islands tend to dissipate the wave energy further offshore. The coastal areas, particularly Santa Barbara Channel, are more protected from wind and waves by the offshore features. Santa Barbara Channel is susceptible to wave attack from the southwest-west, southeast, and the passages of the Channel Islands (wave windows). However, the east and west ends of the Channel are affected differently because of the protection provided by Point Conception, the length of the Channel (fetch), and the orientation of the Channel Island passages with respect to the mainland. The San Pedro area is susceptible to direct wave attack from the south and to a minor extent from the west. Again, the offshore islands tend to protect the area from direct wave attack due to refraction and diffraction.



SWELL ROSE SEA ROSE

A - POINT CONCEPTION

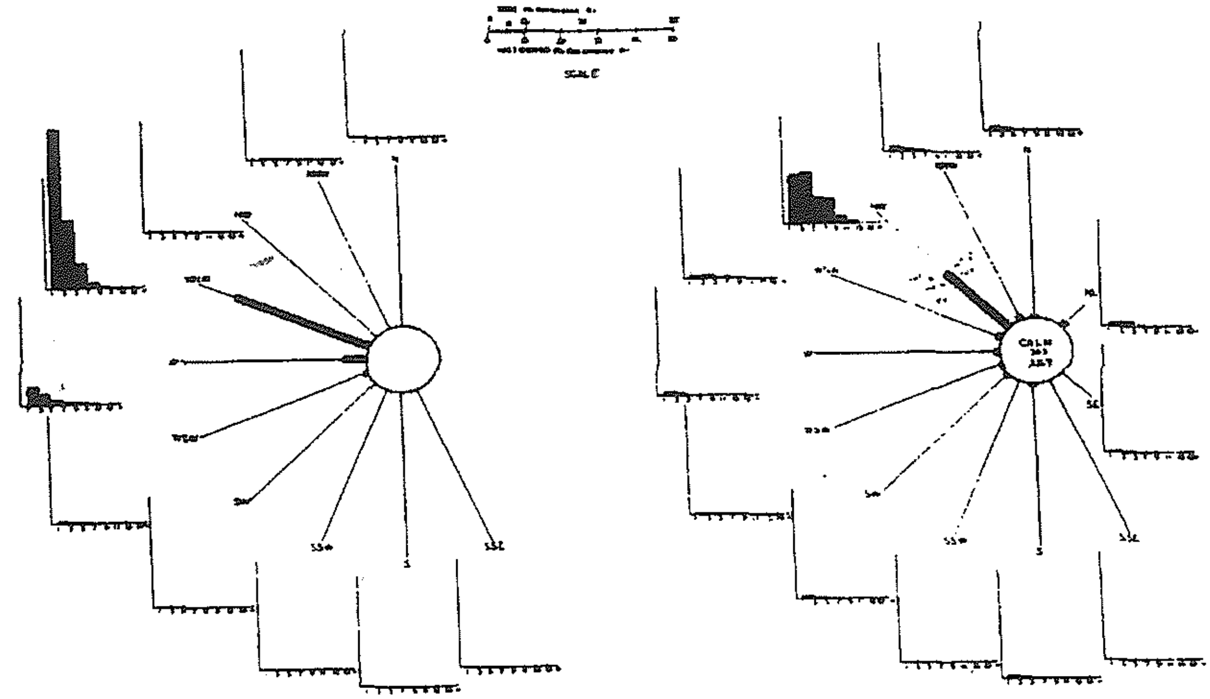


SWELL ROSE SEA ROSE

B - SANTA BARBARA CHANNEL

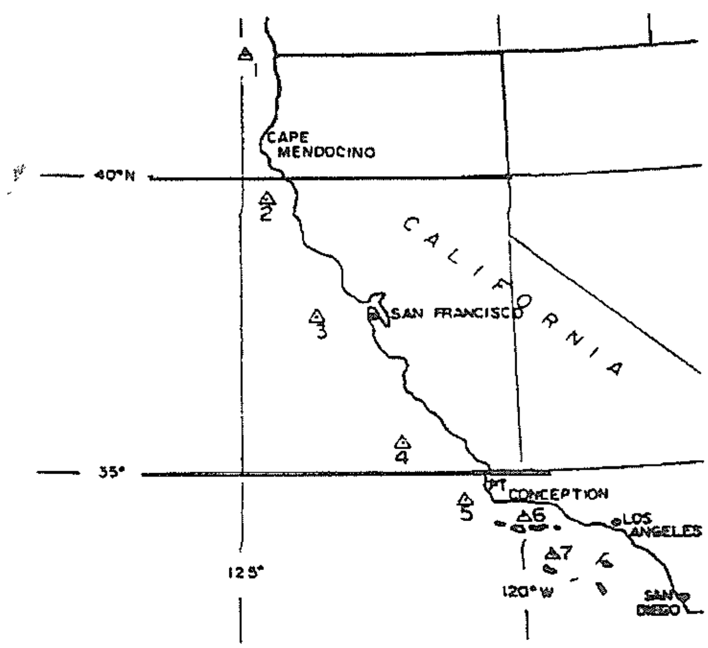
Figure 3.4a-b

AVERAGE ANNUAL SWELL AND SEA ROSES, SOUTHERN CALIFORNIA
(from National Marine Consultants, 1960)



SWELL ROSE SEA ROSE

C - SOUTHERN CALIFORNIA BIGHT



D - STATION LOCATIONS

Figure 3.4c-d

AVERAGE ANNUAL SWELL AND SEA ROSES, SOUTHERN CALIFORNIA
(from National Marine Consultants, 1960)

3.4 Oceanographic Processes

3.4.1 Circulation

Numerous studies have documented the oceanographic features and seasonal trends along the central and southern California coast (Blumberg et al., 1984; Chelton et al., 1982; Brink and Muench, 1986). General current flow patterns are dominated by the California Current System. The California Current is predominantly southward-flowing from the surface to a depth of approximately 200 m that moves along the seaward edge of the continental shelf as far as 1,000 km from shore (Chelton et al., 1982) The northward flowing California Undercurrent is primarily below 200 m and shoreward of the California Current. However, in fall and winter, decreasing wind strength allows seasonal surfacing of the undercurrent north of Point Conception. This surface expression of the northward current is called the Davidson Current. A third component, the Southern California Countercurrent, is a northward-flowing current typically found south of Point Conception and north of the Channel Islands (Brink and Muench, 1985).

The California Current originates off the coast of Washington-Oregon and transports low temperature, low salinity, high nutrient, high oxygenated subarctic water southward. The direction and speed of the current vary yearly and seasonally depending on the states of the Pacific High. At the surface, the Current flows south-southeastward about 600–1,000 km offshore and is generally parallel to the northern and central California coast. Near Point Conception it diverges slightly southwestward from its course. The current is diffuse and extends to 100–500 m depth. Speeds vary from 10– 25 cm/s, although speeds up to 50 cm/s have been observed, particularly in eddies and meanders (Schwartzlose and Reid, 1972; Mooers and Robinson, 1984).

The California Current branches into a north-northwest and south flowing current regime off Baja California. The north-northwest return flow, the Southern California Countercurrent, represents the inshore limb of the cyclonic California Eddy in the Southern California Bight (Figure 3.5). The countercurrent transports high temperature, high salinity, nutrient-rich, oxygen deficient water from the south (Wyllie and Lynn, 1977; Thomas and Seibert, 1974). The countercurrent flows northwest between the mainland and the Santa Rosa-Cortes Ridge-Tanner Bank System and leaves the Bight north and south of the Santa Barbara Channel Islands. In conjunction with the countercurrent is the northward flowing undercurrent which is found at depths of 200–500 m beneath the California Current.

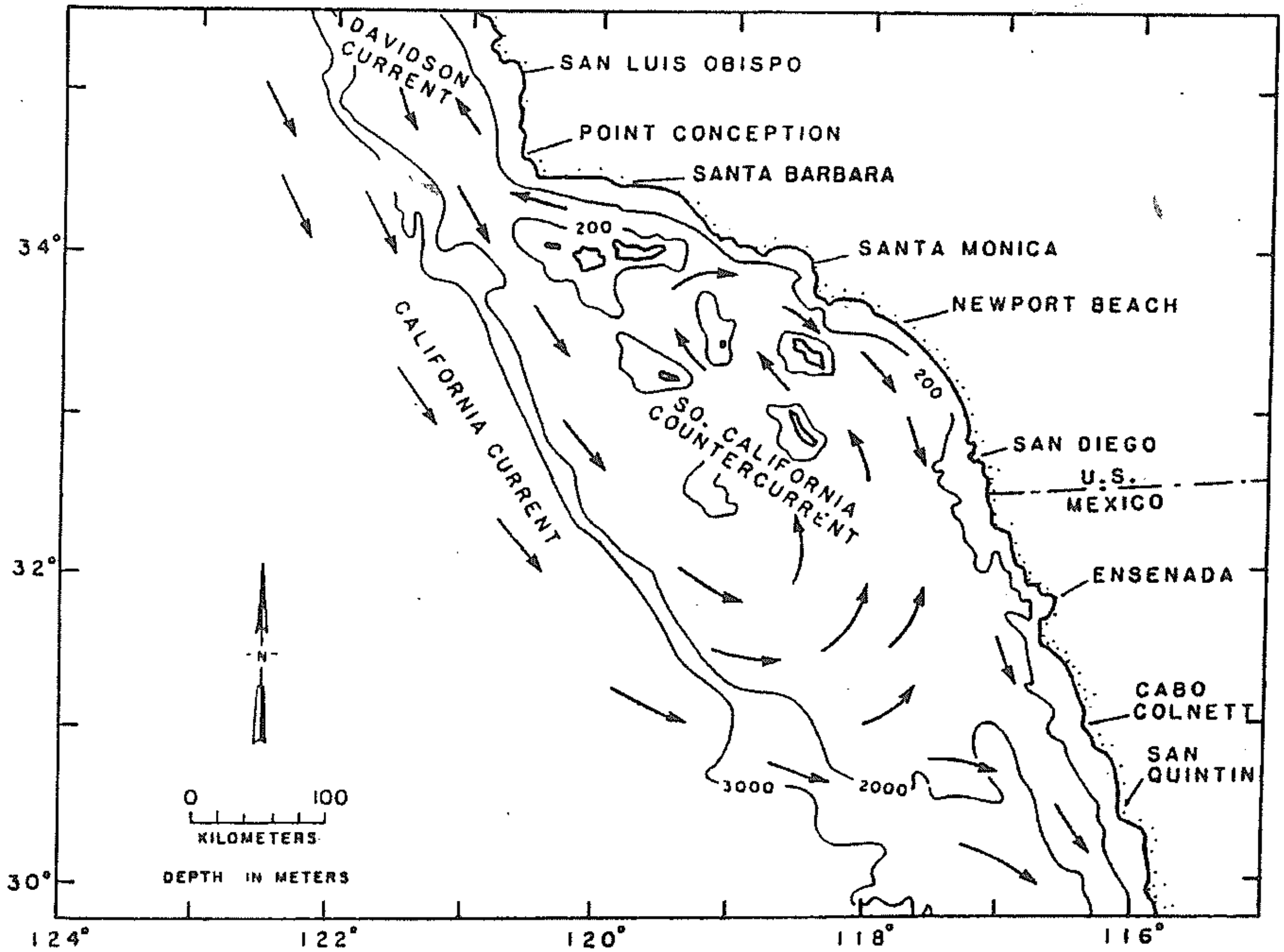


Figure 3.5

SURFACE CIRCULATION (0-100m) IN THE SOUTHERN CALIFORNIA BIGHT
(arrows indicate approximate direction of flow) (from SCCWRP, 1973)

The Southern California Countercurrent varies in speeds from 10–20 cm/sec while the mean speed of the undercurrent is 5–10 cm/sec. The Davidson Current is about 80 km offshore (maximum) and varies in speed from 16–47 cm/s (Reid, 1963; Schwartzlose and Reid, 1972; Schwartzlose, 1963). Depending on the oceanic season, a southward flow is occasionally present landward of the countercurrent. The flow may result from formation of eddies along the coastal areas, particularly near promontories.

Mean current flow in the Point Conception to Point Arguello region is generally parallel to the coastline and bathymetric contours (Chelton et al., 1982). This area also represents a transition region between the poleward flowing warmer water exiting the Santa Barbara Channel, as associated with the Southern California Counter Current (Hickey, 1991), and the cooler, fresher water of the southward flowing California Current (SAIC and MEC, 1995). The local current structure can be quite variable, consisting of numerous transient features such as eddies, filaments, and jets (Mooers and Robinson, 1984). These patterns are also influences strongly by seasonal upwelling events (Brink and Muench, 1986) and interannual variations associated with El Nino/La Nina conditions. El Nino conditions in particular can cause a reduction in seasonal increases in primary productivity (Dugdale and Wilkerson, 1989; Chelton et al., 1982).

3.4.1.1 Surface Circulation and Oceanic Seasons

The seasonal surface circulation in the Southern California Bight is complex and highly variable. In the Bight, the surface and bottom circulation are strongly influenced by the complex topography of the basins and ridges and coastal indentations (Figure 3.5). These features also tend to control the formation and dissipation of eddies and meanders. Sills of the ridges control the exchange of water between the basins and hence, affect not only the water properties of the basins but also the exchange and distribution of sediments, and biological and anthropogenic inputs. Generalized current patterns in the Southern California Bight have been studied extensively over the past decades using direct measurements, drift cards, drogues, and satellite imagery (Sverdrup et al., 1942; Reid et al., 1958; Kolpack, 1971; Drake et al., 1972; Pirie et al., 1975; Hickey, 1979). An overview of the three oceanic seasons is given below followed by a brief description of each season and a very generalized description of surface circulation for specific permit areas.

The three oceanic seasons or periods which tend to control circulation off the California Coast are: the Oceanic Period, the Davidson Period, and the Upwelling Period. The California Current is strongest during the Oceanic Period and is also present during the other periods. Important parameters such as wind, waves, land and submarine topography, and oceanic currents may cause local variations in the presence, absence or persistence of the periods at a given locality throughout the year. The seasons are representative of mean conditions over several years and may be absent or persistent for long periods of time at a given locality due to variations in local and regional conditions.

<u>Oceanic Period (July-August to November)</u> — The Oceanic Period is characterized by the dominance of the southward flowing California Current off the California coast. However,

northward flows may persist all year along certain regions near the coast such as the California Countercurrent in the Southern California Bight (Figure 3.6a).

Central California: a northward flow exists north of Point Arguello and is bounded on both sides by a southward flow.

Santa Barbara Channel: a large cyclonic eddy is prevalent in the western part of the channel which may result from intrusion of part of the California Current into the channel via the west entrance. Currents also enter the Santa Barbara Channel via the San Miguel and Santa Cruz Passes. In the eastern part of the channel, a clockwise eddy(s) may develop over the Oxnard Shelf and Slope due to intrusion of the California Countercurrent at the southeast entrance. A complex pattern, of eddies may result from the convergence of the two eddies in the central channel area between Santa Cruz Island and Santa Barbara (Lagerloef, 1991; Kolpack, 1971; Pirie et al., 1975).

San Pedro Area: a clockwise eddy may exist over the area.

Davidson Period (November-February) — The Davidson Period results from a shift in wind direction from north to south as the Pacific High moves southward. Winds may be weak or absent. The California Undercurrent comes to the surface and becomes the Davidson Current north of Point Conception (Figure 3.6b). During this period, the Davidson Current is the strongest.

Central California: a strong north-northwest flow predominates off the coast from Point Conception-Point Arguello northward. A southward flow exists along the coast.

Santa Barbara Channel: circulation cells in the channel become less obvious. Currents (probably Southern California Countercurrent) enter the channel between the Channel Island passages and the southeast entrance. In the western part, the flow is predominantly westward out of the channel. In the eastern part, a clockwise and counterclockwise eddy(s) may develop with the return flow towards the Channel Islands.

San Pedro Area: a divergence of currents may exist in San Pedro Bay with flows directed southwest and southeast along the coast. Further offshore towards the southwest, a clockwise eddy may exist. A northwest flow exists off Palos Verdes Peninsula.

Outer Region of Southern California Bight: the California Countercurrent shifts westward and possibly northward of the position it occupied during the Oceanic Period.

Upwelling Period (February, March - July, August) — The Upwelling Period is characterized by intense upwelling of cool, nutrient-rich, high salinity subsurface waters off the California coast. The zone of upwelling can extend 50–100 km offshore, over the continental shelf and/or slope and originates at water depths generally <100 m though at maximum of <200–300 m (Bourke et al., 1977). Upwelling occurs when north-northwest winds persist along the coast causing the transport of surface waters offshore and subsequent replenishment by subsurface waters (Reid et al., 1958). Water temperatures 20–30 km offshore can be 5 degrees Celsius warmer than along the coast (Bourke et al., 1977). During this period, the California Countercurrent and Davidson Current may be less persistent or even absent (Hickey, 1979). Upwelling tends to be intense near submarine canyons and south of peninsulas and capes.

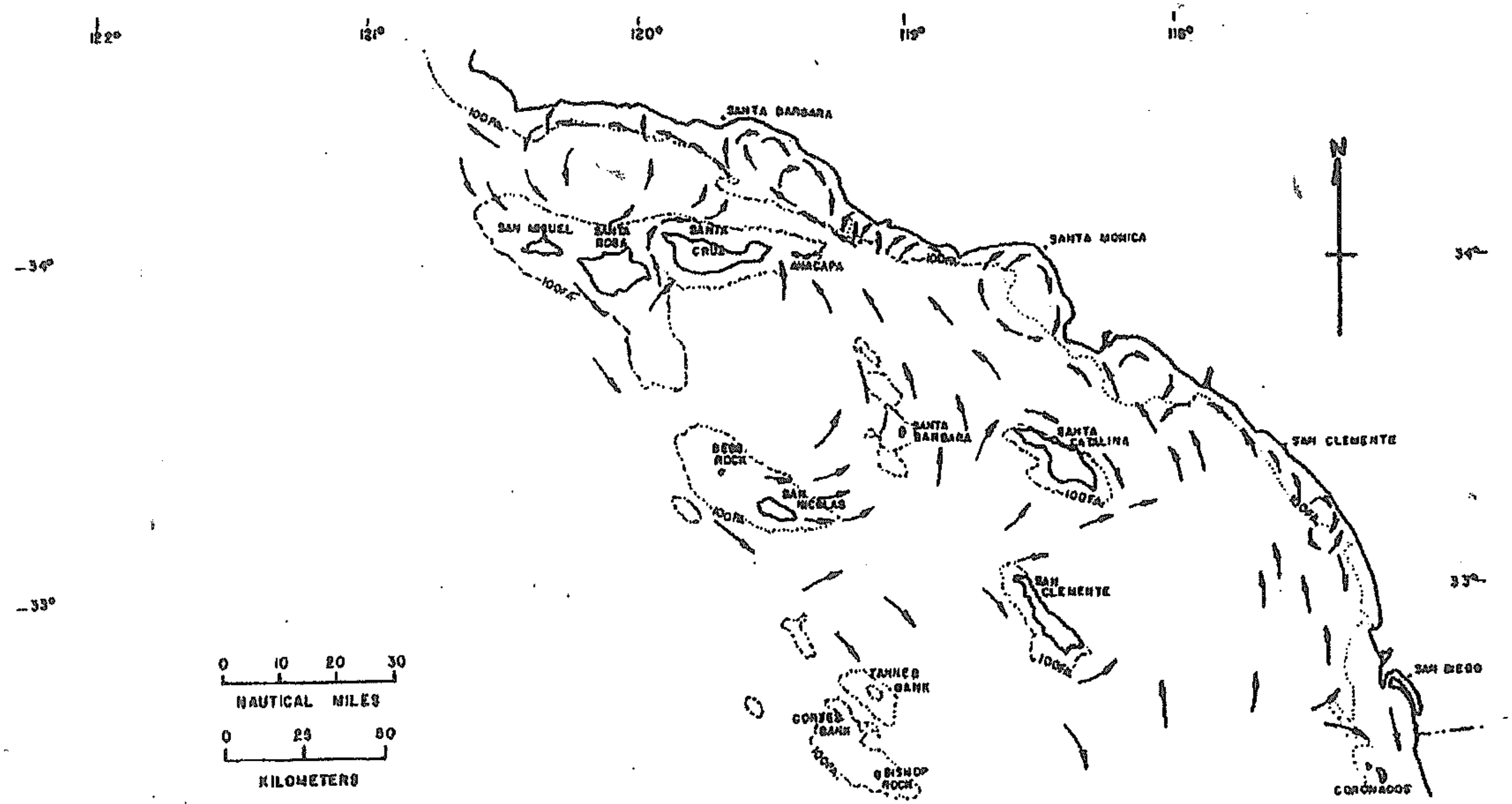


Figure 3.6a

GENERALIZED SOUTHERN CALIFORNIA SURFACE CURRENTS FOR THE OCEANIC PERIOD
(from Pirie et al., 1975)

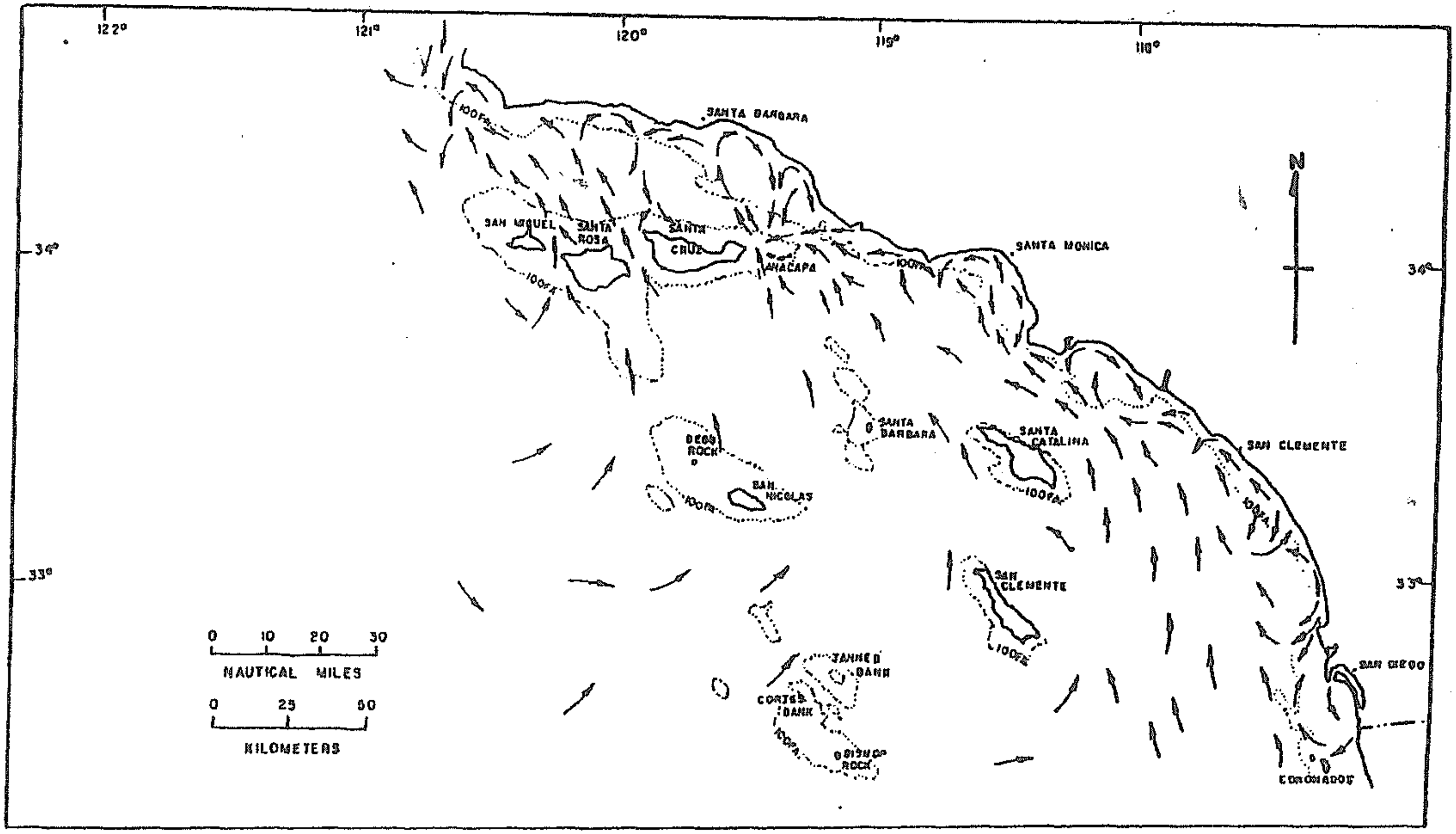


Figure 3.6b

GENERALIZED SOUTHERN CALIFORNIA SURFACE CURRENTS FOR DAVIDSON PERIOD

Source: Pirie et al., 1975

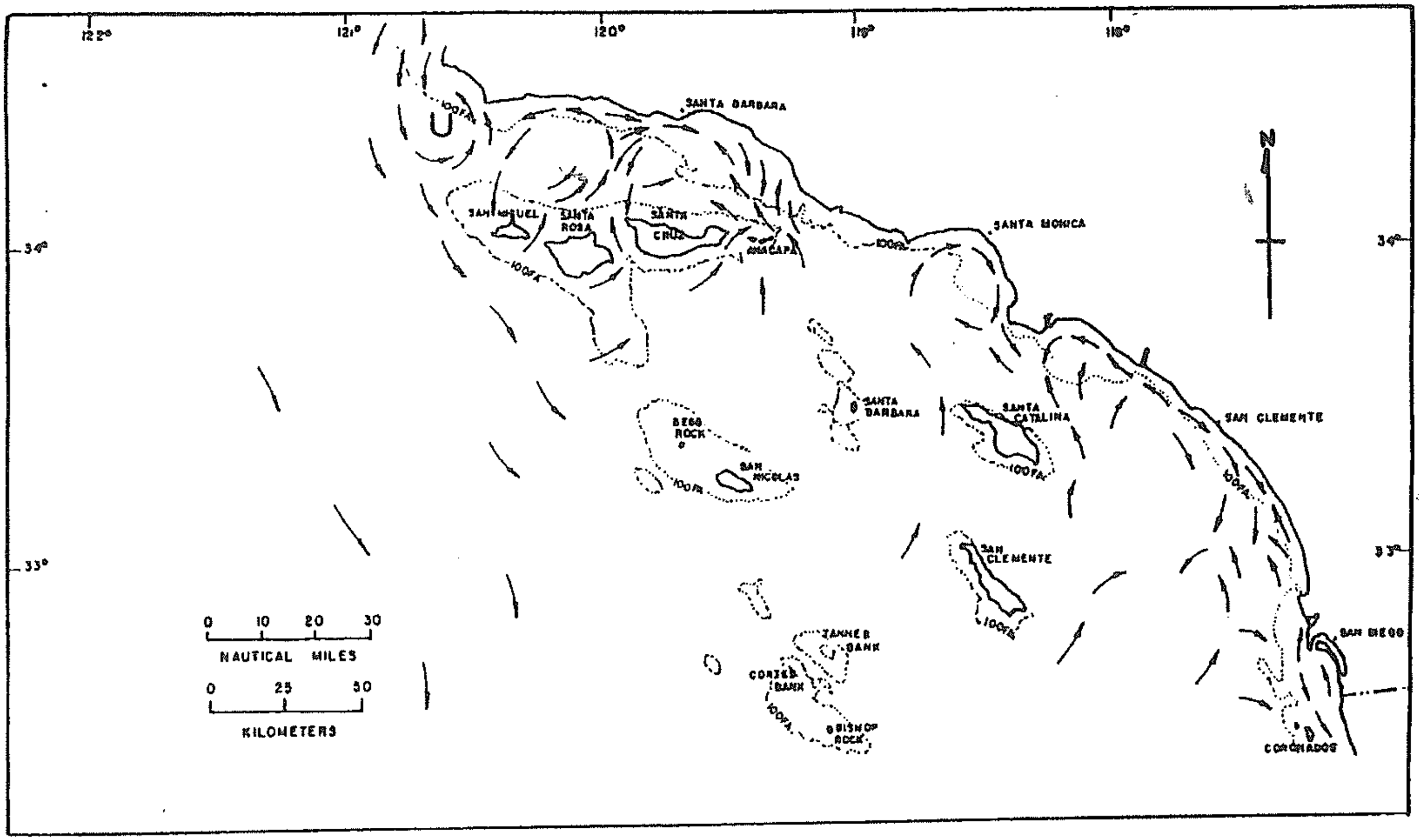


Figure 3.6c

GENERALIZED SOUTHERN CALIFORNIA SURFACE CURRENTS FOR UPWELLING PERIOD

Sour· Pirie et al., 1975

In the California area, intensive upwelling occurs off Point Arguello-Point Conception (Sverdrup et al., 1942). Other sites include the areas of south of Santa Rosa-Santa Cruz Islands. Point Dume, Point Ferman, Point La Jolla, Point Loma of the Southern California Bight and Point Arguello to Point Buchon in areas of the Santa Maria ocean basin.

Central California: a southern flow predominates off the coast areas of upwelling occur near the coast and off Point Arguello-Point Conception. Surface expression of northward flow is not present.

Santa Barbara Channel: a large cyclonic eddy is present along the western part of the channel with a possible divergence of flow in the offshore vicinity of Goleta. Circulation in the eastern part of the channel is speculative due to the complexity of the circulation pattern. An east-southeast flow along the coast of the mainland may tentatively exist.

San Pedro Area: flow in the area tends to follow the bathymetric contours along the continental shelf-slope. The flow originates from the southeast-south direction.

3.4.1.2 Bottom Circulation and Currents

As with surface circulation, bottom circulation is controlled by the complex topography of the basins and ridges of the Southern California Bight. The topography, particularly on the ridges, controls the circulatory patterns of the California Current and Undercurrent and Southern California Countercurrent, the latter two of which flow over the continental shelf and slope.

Bottom transport along and off the shelf occur by oceanic, nearshore and/or tidal currents, wave-induced bottom currents, wave surges, and density flows. On the slope and in the basins, transport can occur via nepheloid flows, oceanic currents, and turbidity flows, in addition to vertical transport via sinking of material. Slumping, sliding, and creep occur, particularly in submarine canyons and areas with steep slopes.

Velocities of the bottom currents/flows are highly variable throughout the permit areas (Figure 3.7), and are dependent in part on the variations in bathymetry (degree of seafloor slopes, areal extent). Constricted areas, such as passages, have high velocities, whereas broad gently sloping areas tend to have slow velocities. Speeds up and down submarine canyons are similar, with typical maximum speeds of 25 - 35 cm/s being reported (Shepard and Marshall, 1969, 1973; Shepard et al., 1939, 1974).

In a Southern California Bight study, current velocities tended to decrease with increasing depth at three moorings located at the west entrance of Santa Barbara Channel immediately off Point Conception (two month record). At 65 m and 135 m depths, bottom velocities ranged from 0 - 52 cm/s and 0 - 43 cm/s, respectively, and mean velocities were 13 - 14 cm/s to the northwest. At 350 m depth, the velocity ranged from 0 - 37 cm/s and had a mean value of 8 cm/s to the southeast (Brink and Muench, 1986).

3.4.2 Water Characteristics

Water temperature and salinity of the permit area are subject to the influence of the California Current System, wind direction, seasonal effects from surface cooling/ heating, and vertical transport by upwelling processes. Directly related to these processes are the effects of local and regional land and submarine topography. High surface temperatures tend to occur after cessation of upwelling, generally in early fall. High surface salinity values tend to occur in summer and fall from the increased evaporation and lack of significant rainfall during the summer (Figure 3.8). Variations in temperature and salinity with depth, and in stratification are due, in part, to the degree of mixing of the different water masses at depth.

There is considerable variation in water temperatures, salinities and densities among the lease tracts (Figure 3.9). North of Point Conception, surface water is cooler (by 2° - 4°C), more saline, and richer in nutrients than in the Southern California Bight. The difference is due, in part, to two regions of upwelling--one region seaward of Point Conception and the other off the Central California coast. In both regions, cool, high salinity, nutrient-rich subsurface water is transported up to the surface.

Strong east/west gradients in temperature and salinity are also prevalent in the permit areas. Temperature generally increases while salinity decreases offshore. This trend is due, in part to upwelling of cool, high saline waters nearshore and transport of warmer, less saline waters of California Current offshore. Bourke et al. (1977) noted that 20 - 30 km off central California water temperatures can be 5°C warmer than along the coast.

3.4.2.1 Temperatures

For the Southern California Bight, surface temperatures tend to increase from north to south (Figure 3.8). Temperatures vary greatly in the upper 100 m, from 11°C to 23°C at the surface to 8.5°C to 16°C at 100 m depth (Churgin and Halminski, 1974). Between 100 - 300 m depth, the temperatures vary from 6.5°C to 11°C (BLM, 1978). The temperature, salinity and density of the deep basins is dependent on the sill depth, which determines the extent and type of water exchange among basins.

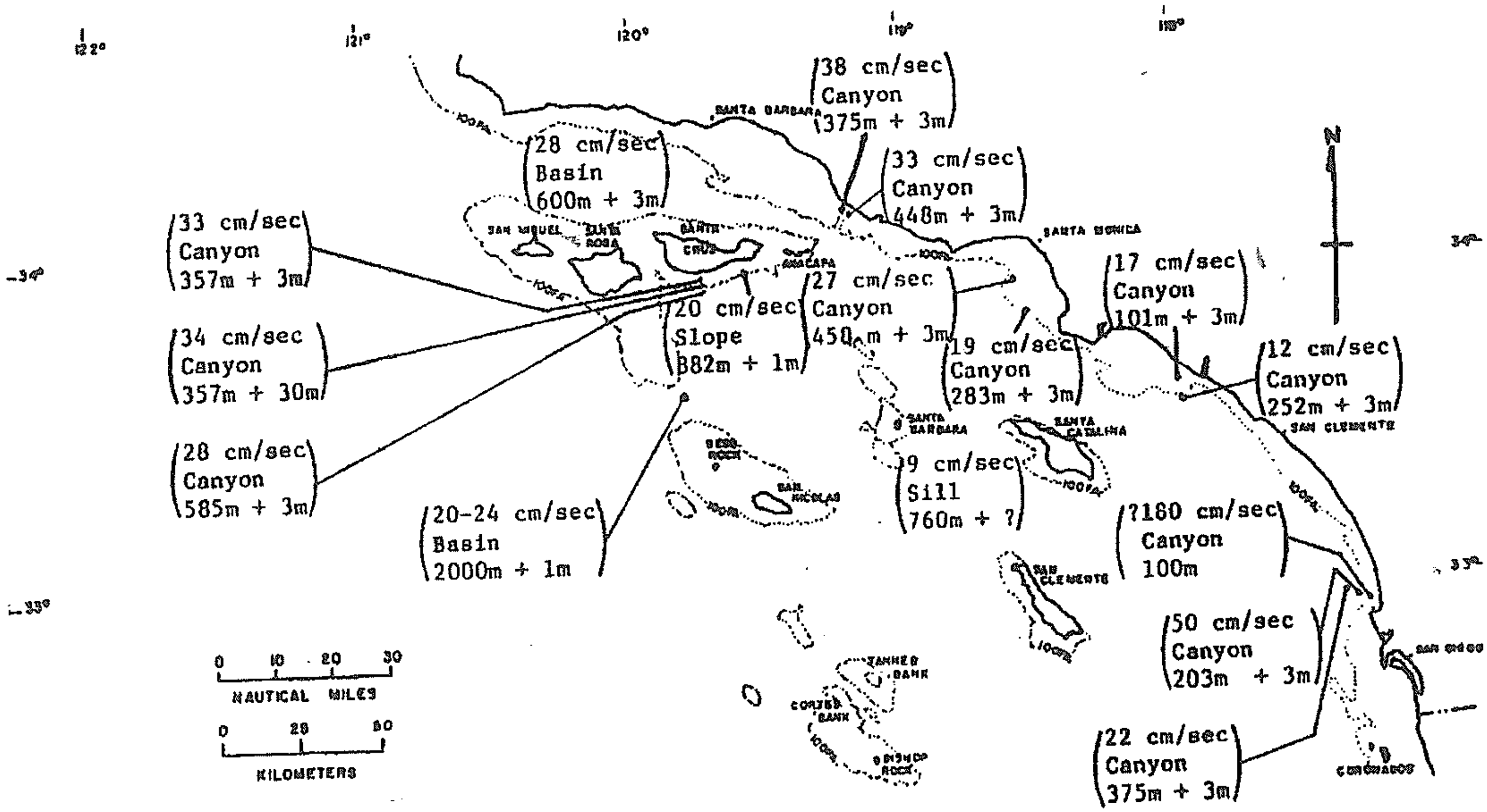


Figure 3.7

OBSERVED MAXIMUM NEAR-BOTTOM CURRENTS COMPILED FROM VARIOUS SOURCES (1939-PRESENT)
(taken from BLM, 1978)

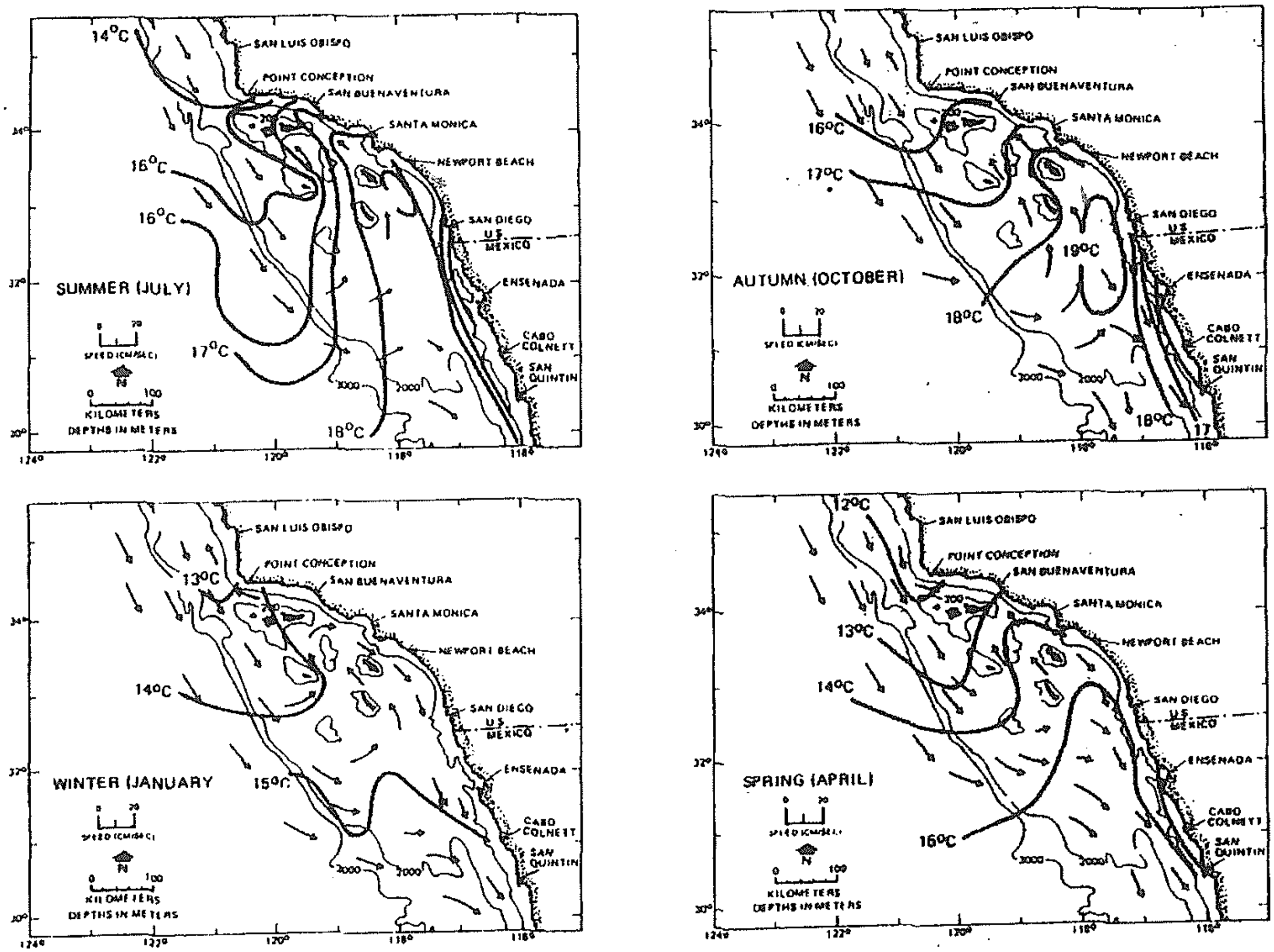
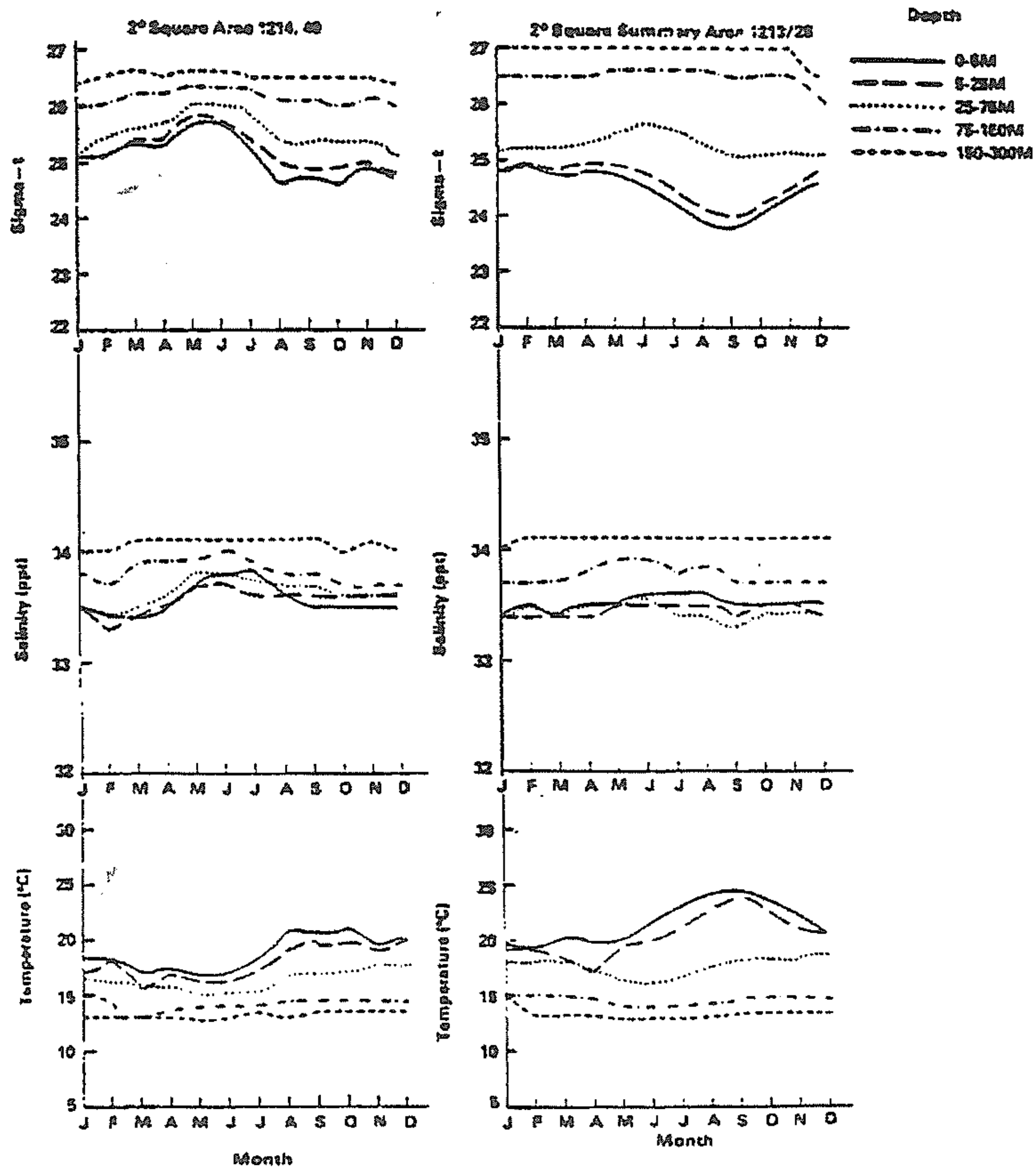


Figure 3.8

AVERAGE GEOSTROPHIC SURFACE FLOW (ARROWS) AND SURFACE ISOTHERMS (DEGREES C) IN THE SOUTHERN CALIFORNIA BIGHT (From Fauchald and Jones, 1971).



A – Pt. Conception

B – San Diego

Figure 3.9

AVERAGE TEMPERATURE, SALINITY, AND DENSITY FOR TWO SOUTHERN CALIFORNIA AREAS

Source: NOAA, 1980

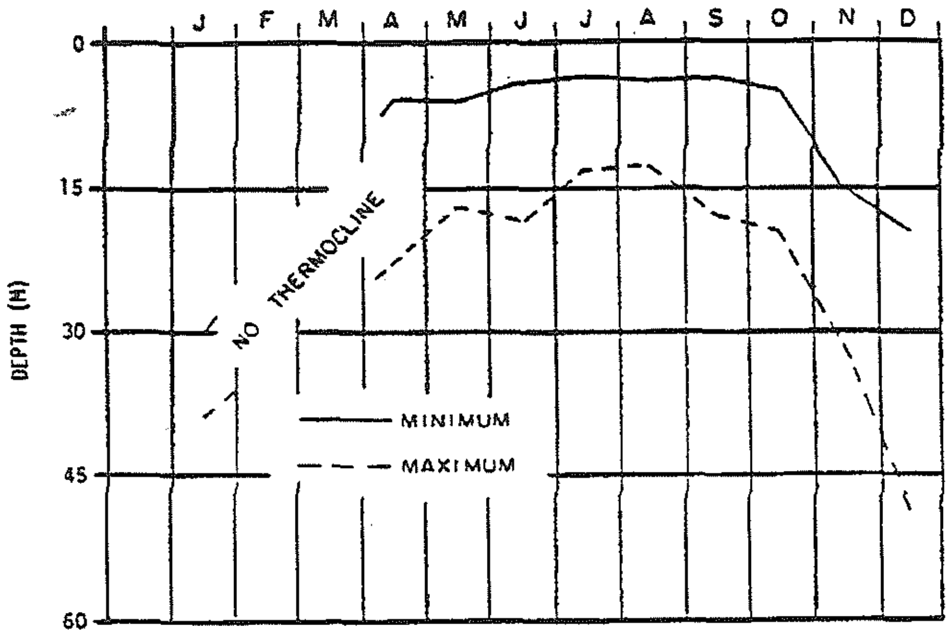


Figure 3.10

AVERAGE MONTHLY MAXIMUM AND MINIMUM DEPTH TO SEASONAL THERMOCLINE
(1957-1960)

Source: Allan Hancock Foundation, 1965

Seasonal and daily temperature variations occur between 10–50 m depth which represents the average depth of the seasonal thermocline (Figure 3.10). Factors affecting the depth of the thermocline include vertical mixing (upwelling, freshwater intrusions), wind waves, swells, internal waves (shelf edge turbulence), winds, tides, and surface heating/cooling. Between 200–500 m depth, a small permanent thermocline exists, resulting from the mixing of the subarctic California Current waters and south-originating waters. Temperatures decrease from 8° – 9°C at 200 m to 5.5 – 6.2°C at 500 m and then slowly decrease towards the bottom (BLM, 1978).

For Santa Barbara Channel, average surface temperatures generally range from 13.5°C during late winter to 18°C during summer and fall (Figure 3.11). Generally, the temperature decreases with depth to a minimum of around 6°C in the central deep basin (600 m). A seasonal cycle is less prevalent with depth and is not noticeable below 100–200 m (Allan Hancock Foundation, 1965; Kolpack, 1971; Lynn, 1967; NOAA, 1980).

For offshore Central California, at the 10 m depth, isotherms (lines of equal temperature) tend to be parallel to the coast. Warmest temperatures occur in fall and range from 14° – 16°C (57° – 61°F) while coolest temperatures occur in winter and range from 11° – 13°C (52° – 55°F). Seasonal maximums in the offshore areas are 16° – 18°C (61° – 64°F) while in the nearshore areas they are 14° – 15°C (57° – 59°F). Maximum temperatures tend to occur earlier in the Southern California Bight than off central and northern California (CALCOFI, 1963; Wyllie and Lynn, 1971; BLM, 1978). At 150 m depth, temperatures ranged from 8.5° – 9.5°C (47° – 49°F) during the Oceanic and Davidson Periods and are cooler during the Upwelling Period (Wyllie and Lynn, 1971).

3.4.2.2 Salinity

For the Southern California Bight, salinities vary from 33.5 to 34.5 ppt and tend to increase with depth due to mixing of the different water masses (California Current and Undercurrent). Gradients are highest at depths above 200 m, before decreasing gradually to the bottom (similarly for temperature). Between 40–600 m, the average salinity of the California Current water is 33.5% which is characteristic of a near surface water mass. The maximum salinity is 34% for the California Undercurrent water at depths between 150–200 m to 500–800 m. The salinity of the undercurrent waters is also higher than the California Current waters. The salinities of the Southern California Countercurrent water range from 33.4 to 34.6 ppt (10 m depth) and represent a mixture of the California Current water and southern water (BLM, 1978). In the Santa Barbara Channel, maximum and minimum salinity values occur in early summer (June–July) and winter (December-January), respectively (Figure 3.11) (Lynn, 1967; Reid, 1965). Salinities at the surface range from 32.5 to 33.5 ppt, while in the deep basins they are fairly constant, about 34.5 ppt. Temporal changes in salinity are produced by the combined effects of upwelling and advection due to the Southern California Countercurrent (Reid, 1960, 1965; Lynn, 1967). In the northern areas of the west coast, upwelling produces salinity maximums during summer. In the southern areas, northward coastal transport produces peak salinity values in winter. In the Santa Barbara Channel, the effects counteract each other, although a salinity maximum in summer is evident.

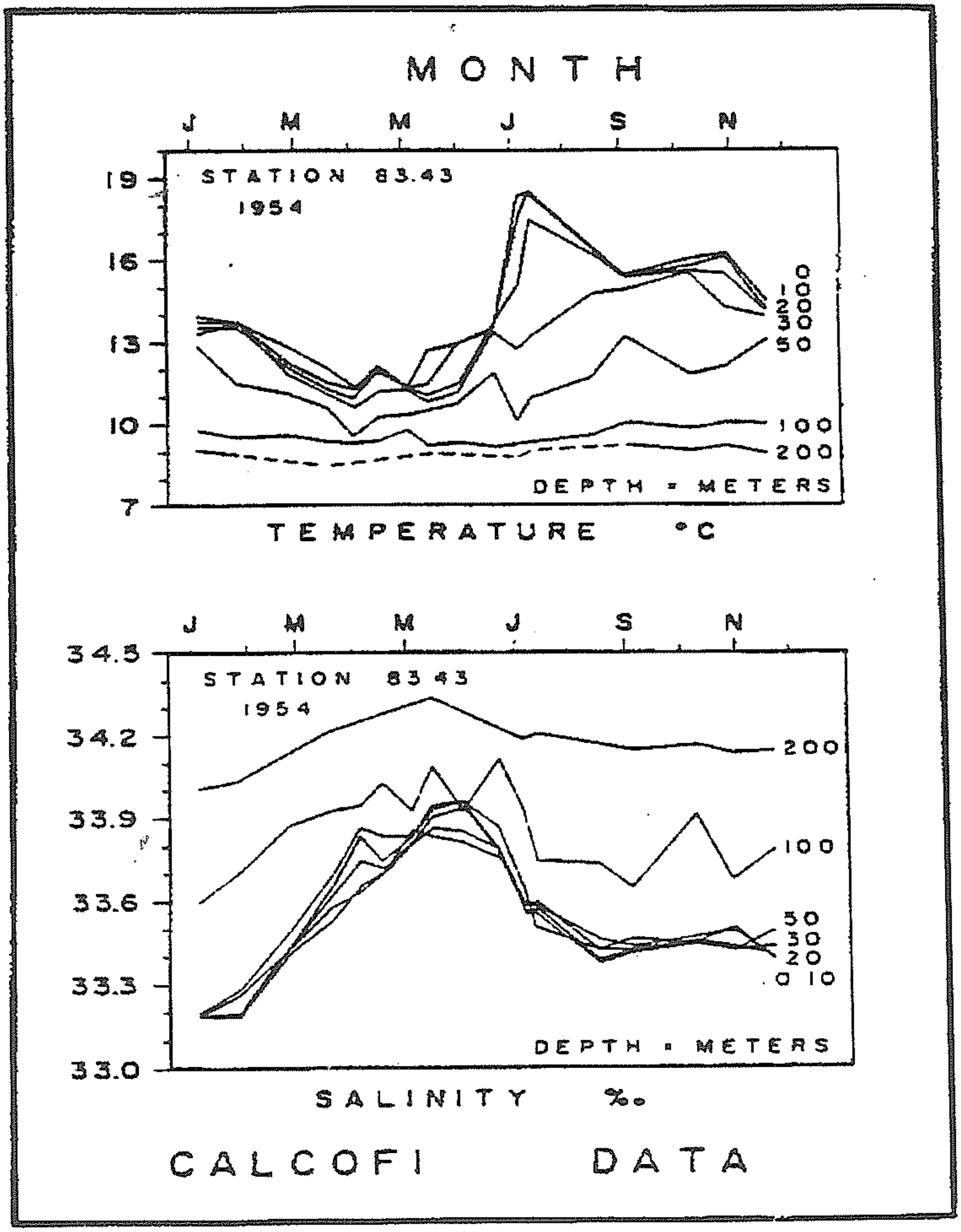


Figure 3.11

SEASONAL CYCLE FOR TEMPERATURE AND SALINITY
FOR SANTA BARBARA CHANNEL (From Kolpack, 1971)

For offshore central California, as with temperatures at 10 m depth, isohalines (lines of equal salinity) tend to parallel the coast. Maximum surface salinities of greater than 33.6 ppt occur during June and July during coastal upwelling. Maximum salinities at 150 m depth occur in the coastal areas during the Upwelling and Oceanic Periods. Minimum salinities tend to occur during winter and spring (Wyllie and Lynn, 1971).

3.4.3 Stratification

Stratification is directly related to the stability of the water column. The presence or absence of stratification is an important mechanism for inhibiting or allowing for the vertical exchange /dispersion/dilution of water and its accompanying components (suspended organic and inorganic sediments and solids, nutrients) in the water column. Factors which influence and/or control stratification and stability include the density of the upper and lower water masses, the density gradient between the masses, and the initial density of the substance being dispersed. Vertical mixing, which can destroy stratification, is controlled by turbulence produced by winds and waves, upwelling, and changes in temperature and salinity with depth among other mechanisms.

The stratification which occurs in the Santa Barbara Channel is similar to that of the Santa Maria Basin and Southern California Bight. Two important factors which contribute to vertical stratification in the waters of the Santa Barbara Channel are: (1) the decrease in temperature with depth, and (2) the increase in salinity with depth. Stability, as previously stated, is directly proportional to stratification and is at a minimum of $20 \times 10^{-6}\ m^{-2}$ during winter and reaches peak values ($55 - 70 \times 10^{-6}\ m^{-2}$) during spring and summer (Allan Hancock Foundation, 1965). The high values in spring and summer and the low values in winter are the result of the seasonal development and erosion of the thermocline. The seasonal cycle could produce variations in the amount of vertical mixing and dispersion of particles. The seasonal variation of density in the upper 50 m of the water column is shown in Figures 3.9 and 3.11. The low stratification in the winter progresses to a stratified regime in the summer and fall with the spring being a transition period. This upper level barrier to vertical mixing would thus be greatest during the summer-fall seasons.

3.5 Sediment Distribution

The distribution and characteristics of sediments in the various permit areas tend to reflect the sediment sources and energetics of the system that are responsible for their transport and redistribution. In some instances, knowledge of the distribution of sediments is useful to understanding the circulation of an area. Sediments are transported as bedload or suspended load, or a combination of both depending on the current velocity. The mode of transport is dependent on sediment size, shape, and density. Mechanisms which initiate, maintain, and/or influence sediment transport include waves, bottom wave surges, tides, local and regional currents, river discharge, sediment supply, and the presence of bathymetric features such as submarine canyons, ridges, and depressions. The complex eddies and meanders which occur along the coast and offshore aid in transporting suspended particulate matter offshore and among the basins. Vertical transport of suspended particulate matter can also occur by aggregation of suspended matter and by fecal pellets.

Generally, there is a gradation in sediment size from inshore to offshore. On the shelf, sediments become progressively finer offshore as the effects of transport by waves, wave-induced currents, and nearshore currents decrease and oceanic currents increase. The transition between processes occurs between 60–100 m depth. Bedrock is exposed on some outer shelves which can reflect lack of sediment supply and/or shelf edge turbulence (internal waves breaking at the shelf break; long period waves feeling the bottom). From the slope to the basins, sediments tend to become finer as currents become less energetic. Besides currents, waves, and settling of suspended matter, mechanisms of transporting sediment to the deep basins include nepheloid and turbidity flows and mass transport by slumping, sliding, and creep.

In the Southern California Bight, the bulk of sediments to the Santa Barbara, Santa Monica, San Pedro Basins and San Diego Trough is terrigenous in origin and is derived from major rivers along the coast, each of which may have different sediment characteristics. Some of these rivers include the Santa Ynez, Santa Maria, Ventura, and Santa Clara Rivers which drain into the Santa Barbara Channel, and the Santa Ana, San Gabriel, and Los Angeles Rivers which drain onto the San Pedro Shelf. Other sediment sources include dusts from winds and sediment contributions from erosion of headlands, longshore and eddy transport (up coast sources), and biogenic origins (shells, tests, fecal pellets). Sediment input from offshore islands is minor.

In the Santa Barbara Channel, the sediment size distribution is complex due to a variety of sediment sources (which contribute different types and sizes of sediment), variable submarine topography, and a complex circulatory pattern of the Channel. MESA[2] (1982) studied the geologic framework of the Santa Ynez lease area in the northwest Santa Barbara Channel. On the Mainland Shelf province between Santa Barbara and Point Conception, sediments grade from medium to fine sands to silty sands to silts. Sediments of the outer shelf tend to coarsen with sporadic outcrops of bedrock. Sediments of the Smooth Slope province are predominantly silts which become finer with increasing water depth. Sediments on the Conception Fan province become finer with increasing depth, grading from fine sands and silts to clayey silts and silty clays. Surficial sediments in the submarine canyons, which incise the Fan, are generally finer than the surrounding sediments.

On the Oxnard Shelf, sediments tend to reflect input from the Santa Clara River. The sediment distribution seems to be controlled by the complex water circulation in the area. Drake et al. (1972) examined sediment movement on the Oxnard Shelf following the floods of 1969. They found fine grained sediments (silts and clays) moved in the offshore direction with time, indicating current and wave conditions were sufficient to resuspend and transport those sizes towards the shelf break. The finest material eventually was transported to the central basin. From the inner shelf seaward, the sediment graded from well sorted sands to poorly sorted silts and clays.

The size distribution around the Channel Islands is similar to the mainland. Gravel is found on the shelf particularly around the passes. There is a gradation of sand to silt to clay with increasing depth. Bottom sediments in the central part of the channel (Central Deep) are predominantly hemipelagic clays and silts with various amounts of organic detritus (Emery, 1960; Fleischer, 1972).

A gradation of sediments is noted on the San Pedro Shelf, although several different sediment groups have been identified (Gorsline and Grant, 1972). Horizontally graded fine sands and silts (silty sands and sandy silts) cover the shelf. Small patches of coarse relict sands are found around a tertiary outcrop in the central area. The pattern of progressively finer sediments offshore is most prevalent from the area between the San Gabriel River and Santa Ana River southwest across the shelf (Gorsline and Grant, 1972; Greene et al., 1975). Sediments at the heads of San Pedro and San Gabriel Canyons are sandy muds which become progressively finer toward the San Pedro Basin. Sediments of the San Pedro Basin vary from very fine silts to clays (Emery, 1960).

Sediment conditions in the Santa Maria Basin area reflect discharges of silts, clays, and sandy materials from rivers and streams, primarily to the north of Point Arguello, and littoral transport of sands from the north and south. Sediments in the vicinity of Platforms Harvest, Hermosa, and Hidalgo consist of approximately 35-85% fines and 15-65% sands with no predominant trends with depth or distance offshore (Steinhauer and Imamura, 1990). The coarse sediments along the coast reflect the high wave energy of the area with presence of rocky headlands and stacks particularly around the southern headlands (Purisima, Point Sal).

3.6 Transport and Fate of Produced Water

The fate of produced water discharges into the marine environment will be governed primarily by physical and chemical processes. Dispersion of produced water plumes can be modeled as a two-step process. The first dispersion phase is associated with the initial rise of the buoyant plume and mixing with ambient sea water until it reaches an equilibrium depth. The second phase involves further mixing and dilution as the plume is transported by local currents away from the discharge point (Washburn et al., 1999). Dilution processes reduce the concentrations of dissolved and particulate phases of the produced water plume at increasing distances from the discharge point. Particle sinking also reduces the concentrations of the particulate fractions of produced water discharges.

3.6.1 Overview of Physical and Chemical Processes Affecting Produced Water Fate and Transport

Physical conditions governing the transport and dispersion of produced water discharges in the receiving environment are currents and density stratification. The release depth also will affect dispersion of a produced water plume because water density and current speeds vary with water depth. For example, the presence of strong water column stratification (i.e., pycnocline) can restrict the depth of the produced water plume following initial mixing to regions immediately above or below the pycnocline, depending on the depth of the release point. Conversely, under weakly stratified conditions, the plume may extend over a relatively larger depth range, leading to proportionately higher initial dilution rates. The presence of the drilling rig or other structures near the discharge point may enhance the dilution due to entrainment of the discharge into the wake of these structures. Dispersion controls the downstream concentration of the discharge and is a function of the hydrodynamic conditions of the area. Sinking of particulate contaminants should also be considered, however, in contrast to drilling muds and cuttings it is assumed that produced water particulates will be primarily fines characterized by low or negative sinking velocities and therefore may not be deposited within the immediate vicinity of the platform. However, flocculation or particle adhesion may enhance the sinking rates of effluent particulates.

In addition to the reduction of contaminant concentration resulting from initial dilution and dispersion, a variety of chemical transformation may alter the initial chemical form of the source material. Adsorption of contaminants onto particles and/or formation of insoluble forms (e.g., barium sulfate) also may increase their removal rate. Trace organic constituents such as petroleum compounds may be affected by differences in solubility and susceptibility to microbial degradation, which affect their persistence and transport potential.

3.6.2 Dilution of Produced Water Plumes

Produced water discharge modeling studies reviewed by Neff (1997b) predict rapid initial dilution of 30- to 100-fold within the first few tens of meters from the outfall. Studies by Washburn et al. (1999) of a produced water discharge at a shallow-water (12 m) site near Santa Barbara predicted minimum initial dilutions of 100 fold in summer to 500 fold in winter. At distances of 1,000 m from the outfall, predicted dilutions ranged from 4,000 to 400,000. The time-average dilution under weakly stratified conditions was estimated as one million times at a distance of 1,000 m from the release point. Measurements of dilution in shallow waters of the Gulf of Mexico (18 m depth) showed a >400-fold dilution at 5 m and >1,000-fold dilution at 50 m from the discharge (Continental Shelf Associates, 1993). Additional studies indicated a 100- and 1,000-fold dilution at distances from the discharge of 10 and 103 m, respectively. These studies indicate that produced water discharges are diluted by at least 100 times within a very short distance from the platform. For existing California OCS platforms, dilution ratios at 100 m have been estimated to range from approximately 500 to 3000 (WSPA, 1999).

3.6.3 Fate of Produced Water Chemicals

Neff (1997b) also reviewed the fate of produced water chemicals and the potential for deposition in sediments. Produced water constituents of greatest concern are the one-ring aromatic compounds (BTEX). For produced waters discharged near the surface, these compounds are thought to evaporate rapidly due to their volatility. Several studies in the Gulf of Mexico demonstrated a 1,000-fold or greater loss of benzene and other BTEX compounds within 100 m of the outfalls. Other studies reviewed by Neff (1997a,b) indicated that PAH concentrations decreased 2,000- (naphthalene) to 12,000-fold (pyrene) at 20 m from a produced water discharge in the Bass Strait off of Australia. An inverse relationship between molecular weight of organic compounds in produced waters and rates of dilution observed during a number of studies probably was due to more rapid evaporation of lighter compounds (Continental Shelf Associates, 1997). The other organic compounds of interest, phenols and mono- and dimethyl phenols are expected to degrade rapidly due to sunlight and bacterial metabolism. Neff (1997a,b) produced water discharges, and that a 1,000:1 dilution would bring most produced water metal concentrations down to ambient levels.

As noted above, BTEX compounds in produced waters are soluble in water and they will not absorb strongly to particulates. Consequently, BTEX compounds are not expected to be deposited or accumulate in bottom sediments. Their concentrations in muds adjacent to produced water discharges are always very low or not detected (Continental Shelf Associates, 1997). However, higher molecular weight organic compounds (e.g., PAHs, aliphatic hydrocarbons) are found in sediments associated with produced water discharges. Discharges in deep, well-mixed waters may produce elevated PAH concentrations within 100 m of the outfall; whereas, elevated PAH concentrations in bottom sediments may extend a few hundred meters for discharges in shallow waters (Neff, 1997b).

Barium concentrations typically are elevated in produced waters as compared with concentrations in receiving waters. For examples, barium in three produced waters from the Gulf of Mexico were 11,000 to 29,000 times higher than concentrations in ambient seawater (Continental Shelf Associates, 1997). Similarly, barium concentrations in produced water samples from Platform Hidalgo were 16.6 mg/L, and considerably higher that expected background concentrations (approximately 0.003-0.019 mg/L) in seawater (SAIC and MEC, 1995). However, barium released to seawater will precipitate as barium sulfate (Neff and Sauer, 1995). Consequently, dissolved barium (the most bioavailable form) concentrations are expected to remain low near a produced water discharge (Continental Shelf Associates, 1997). In a review of three studies of produced water discharges in shallow-water areas of the Gulf of Mexico, Neff (1997b) concludes that little evidence exists of accumulation of metals in bottom sediment around discharge outfalls. Some accumulation of zinc was observed and barium concentrations were elevated above background up to 1,000 m from the discharge points. Additional studies at Gulf of Mexico platforms by DOE (1997) also found that the only produced water metals accumulating in sediments were zinc and barium.

Constituent data for produced water discharges within the Pacific OCS have been compiled by EPA. Analysis of these data indicated that reasonable potentials for exceeding water quality limits were associated only with lead from one discharge source and benzo(a)pyrene from another. These two exceptions may correspond to sampling/analysis artifacts because a higher molecular weight compound such as benzo(a)pyrene is not expected to occur in measurable amounts in produced waters, and lead concentrations in produced waters typically are comparable to those in seawater. Benzo(a)pyrene is more characteristic of a combustion source such as soot particle than a petroleum source.

3.7 Transport and Fate of Drill Muds and Cuttings

3.7.1 Transport of Drill Muds and Cuttings

A number of processes affect the fate of drill mud-derived particulates (Coats et al., 1994). These factors include initial plume dynamics, particle sinking, passive current transport, wave or current resuspension of deposits, and bioturbation. Upon discharge, drill mud plumes are dispersed and diluted by local currents, while gravitational forces act to deposit the drill cuttings and heavier aggregates of drill mud. Drill cuttings are not expected to be transported beyond 200 m of the discharge point (de Margerie, 1989). Approximately 20% of the drill mud particulates may be removed in this near-field deposition process (Continental Shelf Associates, 1985). The remaining lighter material remains in the water column and is subject to passive dispersal over longer distances.

MMS recently conducted studies of long-term impacts from drilling operations at three platforms off Point Arguello (see Section 2). Results from these studies provide information concerning the transport and fate of drill muds and cuttings within the Southern California Planning Area. In particular, Coats (1994) and Steinhauer et al. (1994) examined the dispersion of drill mud particulates, using barium concentrations in suspended particles as a marker of presence of drill mud and particle transport models to predict deposition of drill muds on the sea floor and exposure conditions for bottom-dwelling organisms. Peak predicted and measured sediment fluxes of 400–500 mg/m2/day occurred during drilling at distances within 500 m of Platform Hidalgo (Hyland et al., 1994). Small accumulations of drill mud were observed about 4.5 km from the platform.

Additional modeling of drill mud discharges from these platforms, based on actual discharge rates and particle sizes of muds used during drilling operations predicted that approximately 50% of the total mass of muds discharged would be transported out of the immediate area and would not contribute substantially to the drill mud deposition flux (SAIC and MEC, 1995). Of the total mass of drill muds predicted to settle within the study area, only the coarse fraction would be deposited near the platforms, while the silt and clay sized particles in the drill muds would be widely dispersed. This conclusion was consistent with assumptions used by Coats (1994) that only 20% of the drill muds released from Platform Hidalgo would be deposited near the base of the platform. Further, based on actual discharges from Platforms Hermosa and Hidalgo, and corresponding current patterns, mean depositional thickness of drill muds were predicted to range from 1.5 to 7.3 microns over relatively large areas of the ocean bottom. These mean drill mud depositional thicknesses would result in upper limit increases in sediment barium concentration of approximately 1% (SAIC and MEC, 1995).

Within one year of completion of drilling, the residual excess barium remaining in sediments within 500 m of Platform Hidalgo represented approximately 10% of the total barium mass emission from the platform. The residual barium likely was associated with the heavier cuttings particles and coarser grained particles in the drill muds that were deposited near the base of the platform (SAIC and MEC, 1995). Similar conclusions have been obtained from studies of platform discharges in the Gulf of Mexico (Boothe and Presley, 1985) and off Nova Scotia (de Margerie, 1989).

3.7.2 Fate of Drill Mud Constituents

Steinhauer et al. (1994) examined the distribution of drill mud metals and organic constituents in bottom sediments at near- and far-field stations around Platform Hidalgo before, during, and after drilling operations. Near-field stations were all <2 km from the platform and far-field stations were more than 4.5 km from the platform. Contaminant concentrations in surficial sediments at these locations are listed in Table 3.1.

Two analytes, total petroleum hydrocarbons and barium, showed significant spatial or temporal concentration differences that might have been related to drilling activities (Hyland et al., 1994). Barium concentrations increased by 20% at the nearfield stations during drilling. Although concentrations declined in the 1-2 years after drilling ceased, barium concentration were still elevated by about 100 ug/g over pre-drilling conditions. Total hydrocarbons during the drilling phase exhibited nearly two-fold increases over levels before and after drilling. Although total hydrocarbons concentrations increased during drilling, similar increases in PAH concentrations were not observed, suggesting that the total hydrocarbon signature reflected weathered oil inputs from natural seeps which are a common component of sediments in the Southern California Bight, and were not an indication of changes attributable to drill mud discharges.

Phillips et al. (1998) subsequently investigated additional barium input to the area as a result of drilling during 1993–1994. They observed only minor increases in barium inventories which is likely due to the lower volumes of drill muds discharged during this period.

In total, the first phase of drilling at these platforms resulted in increased barium concentrations of 10-40% in bottom sediments and 200-300% in suspended particles (Steinhauer et al., 1994). Elevated barium concentrations is suspended particles persisted throughout the drilling period, and then decreased within a period of 1 to 1.5 years to background concentrations. In contrast, barium concentrations in surface sediments did not return to pre-drilling levels but remained approximately 10% higher than background. The first phase of drilling did not alter concentrations of other metals or hydrocarbons in bottom sediments or suspended particles (Steinhauer et al., 1994; Hyland et al., 1994). Similarly, discharges of drill muds, cuttings, and produced waters during the second phase of drilling and production had minimal effects on metal and hydrocarbon concentrations in bottom or suspended sediments (SAIC and MEC, 1995). The exception was slightly elevated barium concentrations in sediments in the immediate vicinity of the platforms. Because average barium concentrations in waste materials were up to 150 times higher than background sediment concentrations, and barium is relatively insoluble, subsequent deposition of barite or barium adsorbed to cuttings are expected to be detectable from measurements of the barium signal in sediments or suspended particles (Hyland et al., 1994). The absence of changes in other metals and hydrocarbons is attributed to several factors. Concentrations of metals in the drill muds and cuttings, except for the enriched barium and occasionally elevated zinc and lead in contaminated cuttings, generally were comparable to background concentrations in bottom sediments. Consequently, platform wastes were not expected to substantially alter the concentrations of metals other than barium (Steinhauser et al., 1994). Similarly, hydrocarbons in the study area are characterized by large and temporally variable background concentrations. The petroleum hydrocarbons most highly enriched in the platform wastes, particularly the lower molecular weight PAHs, are relatively soluble and therefore expected to partition readily from particulate to dissolved phases of the discharged drilling mud (e.g., Boehm et al., 1989). Although concentrations of these hydrocarbons were present in muds and cuttings at concentrations several orders of magnitude above background sediment concentrations, any contributions from platform discharges to concentrations of petroleum hydrocarbons were either masked by the dominant background signal of hydrocarbons from natural sources (e.g., local seeps) or reduced due to selective solubilization and /or microbial degradation of these less refractory compounds (SAIC and MEC, 1995).

While the results from these studies suggest that drill mud discharges may be widely dispersed in the offshore marine environment, detailed chemical analyses demonstrate that platform discharges do not cause significant increases in concentrations of chemical contaminants in areas immediately beyond the base of the platform. Studies conducted in the Gulf of Mexico indicate that the mass of waste particles deposited in the vicinity of closely spaced platforms may be directly additive (Boothe and Presley, 1985); whereas other studies (Continental Shelf Associates, 1983) concluded that discharges from multiple wells affected the thickness of deposited particles but not the magnitude of barium enrichment in bottom sediments.

An evaluation of compliance with water quality criteria for discharges of drill muds was performed by the Western States Petroleum Association and submitted as a comment on the draft version of the ODCE. The evaluation followed an approach used in ODCEs prepared for general permits by other EPA regions. The analysis of drill mud discharges was based on a representative drill mud with a density of 17.4 lb/gal, with constituent concentrations considered representative of muds used for OCS operations. Dilution rates were determined using the Offshore Operators Committee (OOC) dispersion model, which has been verified for use in Pacific OCS operations (O'Reilly et al., 1989). The model predicted dilution factors of 1,803 for solids and 1,721 for aqueous phases at a distance of 100 m from the discharge point (i.e., the edge of the designated mixing zone). Applying these dilution factors to constituent concentrations in the source drill muds yielded concentrations below the respective criteria for all components (metals and naphthalene) except beryllium (which exceeded the criterion by about 30%). However, it should be pointed out that the criterion for beryllium cited in the submittal is no longer being used by EPA, nor has EPA developed a replacement criterion (63 Fed. Reg. 68354). As such, EPA does not believe that the result would constitute an exceedance of Federal water quality criteria.

Table 3.1. Mean Contaminant Concentrations on Surficial Sediments from Nearfield and Farfield Stations Before, During, and after Drilling at Platform Hidaglo (Hyland et al., 1994). Control Site Is at Location Proposed for Drilling at Platform Julius.

Chemical (ug/g)	Pre-Drilling Near - Far	During Drilling Near - Far	Post-Drilling Near - Far	Control Site
Silver	0.13 - 0.13	0.09 - 0.09	0.08 - 0.08	0.09
Arsenic	9.7 - 6.7	11.0 - 6.8	9.7 - 6.8	5.9
Barium	764 - 789	970 - 872	888 - 853	740
Cadmium	0.56 - 0.59	0.62 - 0.61	0.58 - 0.58	0.45
Chromium	124 - 131	120 - 127	123 - 139	80
Copper	15 - 16	16 - 14	15 - 15	15
Mercury	0.067 - 0.075	0.085 - 0.088	0.054 - 0.063	0.078
Nickel	40 - 44	39 - 42	40 - 43	39
Lead	14 - 17	13 - 15	14 - 14	15
Vanadium	54 - 63	48 - 53	51 - 54	57
Zinc	75 - 66	76 - 63	74 - 63	64
Total Hydrocarbons	49 - 41	93 - 93	50 - 67	62
Sum PAHs	0.29 - 0.08	0.07 - 0.08	0.03 - 0.02	0.12
Naphthalenes	0.056 - 0.010	0.014 - 0.014	0.002 - 0.002	0.015
Fluorenes	0 - 0	0 - 0	0 - 0	0.004
Phenanthrenes	0.060 - 0.021	0.013 - 0.010	0.005 - 0.004	0.029
Dibenzothiophenes	0.033 - 0.001	0.005 - 0	0 - 0	0.007

4. TOXICITY AND BIOACCUMULATION

Two primary environmental concerns associated with OCS platform discharges to the ocean are: (1) wastes may be toxic to marine organisms; produce harmful sublethal responses, or alter ecosystems; and (2) chemical constituents (e.g., metals and hydrocarbons) may accumulate in tissues of organisms at concentrations that are harmful to the organisms or to consumers, including humans (NRC. 1983). This section discusses the potential toxicity of platform discharges and contaminant bioaccumulation in marine organisms exposed to platform wastes.

4.1 Drill Muds

Assessments of impacts from drill muds on marine biota are based on both laboratory toxicity testing and in situ experiments or observations. Related studies of drilling operations in California waters have included pre- and post-drilling analyses of sediment contaminants and health of benthic communities in the vicinities of active platforms to determine the long-term effects of discharges on the benthic environment.

Laboratory toxicity studies have focused primarily on assessments of acute responses of adult test organisms to particular drilling muds. General caveats pertaining to the applicability of these studies are provided below:

- Lab exposure studies may not account for the ability of a motile organism to leave an area affected by discharges.
- Lab studies may not replicate water movements/or particle settling characteristics.
- "Standard" specie(s), geographical range, sex, and life stage may not represent all species' sensitivities.

All laboratory results and some experimental field studies must be interpreted with an understanding of how their results may be influenced by specific oceanographic and operational factors (Table 4.1). The magnitude or importance of these factors will vary from site to site as well as from operation to operation.

Despite these shortcomings, it is believed that toxicity tests provide valuable information that can be utilized for regulatory requirements. Test species selected, while not representing every environment or organism, are believed to fairly depict a range of sensitivities typical of most biological communities. These test species can also provide predictive capability for impacts to similar organisms. Petrazuollo (1983) noted that "the frequency distribution of LC50 values indicate that a regulatory analysis based on worst case data will be adequate to afford reasonable and conservative degree of environmental protection."

In general, reviews of extensive data from exposure assessments (Neff, 1987; NRC, 1983) have concluded that most water-based drill muds used in OCS drilling operations have low acute and chronic toxicities to representative marine organisms. NRC (1983) identified diesel fuel and biocides as the most toxic constituents of drill muds. However, discharges of oil-based muds to the ocean is prohibited by EPA. Therefore, impacts to marine organisms from discharges of oil-based drill muds are not anticipated. Previous studies have also identified chrome lignosulfonates and sodium hydroxide as moderately toxic. However, chrome lignosulfonates are no longer approved for use; and other mud additives must be tested prior to approval to demonstrate they are not acutely toxic to marine organisms. The toxicity of sodium hydroxide is attributable solely to elevated pH levels (Neff, 1987). Because seawater is a highly buffered system, discharges containing sodium hydroxide are not expected to appreciably alter the pH of receiving waters or cause impacts to marine organisms.

Two of the primary components of drill muds, barite and bentonite, are considered essentially inert with negligible potentials for acute toxicity to marine organisms (Neff, 1987). However, previous studies have indicated some potentials for drill mud particles to cause physical impacts, such as clogging or burial, especially to epibenthic organisms attached to hard substrates. During studies of long-term impacts of drilling and production operations in the Santa Maria Basin, significant reductions in abundance of four out of 22 common hard-substrate taxa on deeper reefs (160-212 m) coincided with active drilling operations from adjacent platforms (Hyland et al., 1994). Estimated exposures of organisms to discharged drill muds were considered to be too low to cause toxic responses. The observed changes in abundance of these taxa were hypothesized to be influenced by physical effects associated with increased particle loading which could result in disruptions of suspension feeding, respiration, and/or post-larval survivorship due to burial (Parr et al., 1994; Hyland et al., 1994).

Table 4.1 Oceanographic and Operational Factors Affecting Concentrations of Drill Mud near Drilling Locations (Geyer, 1980).

- Mineralogical and chemical composition of mud
- Rate of discharge
- Duration of discharge
- Quantity of "wash-down" water used to flush effluents down discharge pipe, which also can cause considerable pre-dilution
- Speed and direction of water currents
- Wave regime
- Eddies caused by water flow around the rig
- Depth of mixed layer (determined in general by thermocline, but could be controlled by any pynocline)
- Density of water beneath mixed layer (light particulates could float along on isopycnal surface and hence be concentrated and transported)
- Fractionation of different phases of drilling fluid, i.e., light and heavy particulate fractions and dissolved fraction
- Depth of discharge pipe
- Water depth
- Type of bottom

4.1.1 Short-Term Lethal Effects Studies

Petrazuollo (1983) analyzed the results of short term lethal bioassay tests of drill muds from a variety of studies. In these studies, 68 drilling fluids were tested and 70 species representing 59 genera were used (Table 4.2). Table 4.2 presents the frequency distribution of the short term LC50 (concentrations causing 50% mortality) values. The frequency distributions may be summarized by class as follows:

Class	LC50 (ppm)	Raw Frequency	Normalized Frequency
I	>100,000	44%	40%
II	10,000-100,000	46%	42%
III	1,000-10,000	6%	10%
IV	100-1,000	1-2%	2-4%

Based on these results, potentials for acute lethal toxicities from exposures to drill muds are considered very low (Petrazuollo, 1983). Further, the liquid and suspended particulate phases of the eight generic drill mud formulations were tested in a series of bioassays (described by Neff, 1987). For all tests, 97% of the LC50 values were greater than 10,000 ppm, and 75% of the LC50 values were greater that 100,000 ppm mud added. Thus, the toxicities of these generic drill mud formulation were considered among the least toxic of drill muds tested (Neff, 1987).

Table 4.2 Data Frequency Distribution of 48 to 144-hour LC50 Values for Drill Muds (From Petrazuollo, 1983).

Taxon	Number Spp.	Number Fluids	Fluid Fraction	Number Tests	Upper Concentration Criterion (ppm) 999	9999	99,000	>100,000	ND
Phytoplankton	1	9	WM	12	0	7	0	0	5
Copepods	1	9	WM	11	3	5	2	0	1
Isopods	1	4	WM	6	0	0	1	5	0
Amphipods	4	8	WM	16	0	0	7	9	0
	1	3	MAF	6	0	0	0	6	0
Mysids	2	8	WM	11	0	0	6	5	0
	3	13	MAF	35	0	0	18	16	1
	2	9	SPP	17	0	1	5	11	0
	1	1	LSP	1	NA	NA	NA	NA	NA
Shrimp	7	16	WM	29	1-6	1	14	8	0
	7	10	MAF	32	0	3	18	11	0
	1	1	SPP	3	0	0	3	0	0
	1	1	SPP	2	0	1	1	0	0
Crab	5	10	WM	16	0	3	7	6	0
	6	10	MAF	15	0	0	9	5	1
	1	1	SSP	1	0	0	1	0	0
Lobster	1	2	WM	3	0	0	3	0	0
	1	2	MAF	4	0	1	0	3	0
Gastropods	5	5	WM	6	0	0	2	4	0
	2	3	MAF	4	0	0	0	4	0
Bivalves	7	12	WM	17	0	1	9	7	0
	4	5	MAF	11	0	0	1	10	0
	2	4	SPP	10	0	0	7	3	0
	2	1	SSP	2	0	0	2	0	0
	4	9	LSP	10	NA	NA	NA	NA	NA
Echinoderms	1	2	WM	2	0	0	1	1	0
	1	2	MAF	2	0	0	0	2	0
Polychaetes	3	12	WM	13	0	0	3	10	0
	4	5	MAF	15	0	0	6	9	0
	1	1	LSP	3	NA	NA	NA	NA	NA
Archiannelids	1	1	MAF	3	0	0	3	0	0
Finfish	12	34	WM	76	0	2	47	27	0
	6	7	MAF	12	0	0	3	9	0
Total	**70**	**68**	**5**	**415**	**4-9**	**25**	**179**	**171**	**8**

ND	Not Determined	WM	Whole Mud	MAF	Mud Aqueous Fraction
SPP	Suspended Particulate Phase	SSP	Suspended Solid Phase	LSP	Layered Solids Phase

Petrazuollo (1983) derived a rank ordering of species/taxa sensitivities to the toxicity of drill muds by summing the product of the Class Index (I through IV, see above) and the relative frequency of that class for a species group. Those results are as follows:

Group	Index Value
Copepods (zooplankton)	310
Phytoplankton	300
Shrimp	199
Decapods (combined)	191
Crab	175
Lobster	171
Finfish	161
Mysids, Bivalves	149
Annelids	139
Amphipods	132
Echinoderms	125
Gastropods	120
Isopods	117

Index values of 400 and 100 represent extreme sensitivity and relative insensitivity, respectively. Based on the values derived from this ranking system, only zooplankton (copepods) and phytoplankton reflect relatively high sensitivity. Petrazuollo (1983) indicates that from all the studies examined, the most sensitive species tested was the copepod, *Arcartia tonsa*, with an LC50 (96-hr) of 100 to 230 ppm. Dock shrimp larvae (Stage I), *Pandalus danae*, was next with an LC50 (144-hr) of 500 to 3,000 ppm. Third was the marine alga *Skeletonema costatum* with an LC50 (96-hr) in the range of 1,325 to 5,700 ppm. Although this ranking was based on a large number of tests, the conclusions should be viewed cautiously because the number of representatives of various taxa is not sufficiently large to characterize the possible range of sensitivity within each taxaonomic group (Neff, 1987). In general, larval, juvenile, and molting crustaceans are considered more sensitive to drill mud exposures than other taxa and life stages (Neff, 1987).

4.1.2 Short-Term Sublethal Studies

Studies of sublethal or chronic effects from drill mud exposures have been conducted with more than 40 marine taxa. However, many, of the studies of sublethal effects used oil (diesel)-based or chrome lignosulfonate muds, which are not currently acceptable for discharge to the ocean. Regardless, in most cases, sublethal responses were observed at exposure levels only slightly lower than those that cause acute toxicity (Neff, 1987).

General categories or responses observed from these earlier studies can be classified as biochemical/physiological or behavioral. As discussed by Neff (1987), chronic effects associated with these more toxic mud formulations were observed at concentrations as low as 10-100 ppm. However, minimal initial dilution rates (e.g., 100 times) following discharge would significantly reduce the concentration and toxicity of the mud discharge. Further, fractionation of the drill mud would occur during dispersion of the plume, thereby altering the nature of the exposure condition. Consequently, when compared to laboratory-based sublethal bioassays, water column organisms are not expected to be exposed to plumes of unfractionated drill muds for a sufficient period of time to induce sublethal changes (Neff, 1987).

The toxicity of used drill muds from Platform Hildago in the Santa Maria Basin to the red abalone (*Haliotis rufescens*) and brown cup coral (*Paracyanthus srearnsii*) was measured in laboratory studies conducted by Raimondi et al. (1997). Using sediment trap data collected previously for MMS (Coats et al., 1994; Hyland et al., 1994), effects of drill mud exposure on fertilization, development, and settling success in the red abalone and adult mortality and tissue loss in the cup coral were assessed using realistic exposure concentrations of 0.002, 0.02, 0.2, 2, 20 and 200 mg/L. No significant effects of drill mud exposure on fertilization or early development stages of the red abalone were observed. Significant negative effects on the ability of larvae to respond to a natural settlement inducer, however, occurred at concentrations at 2 mg/L and greater. The authors noted that the cause of this response (i.e., physical or chemical effects) could not be determined and the ecological significance of settlement inhibition was not determined.

In longer term exposures to drill mud (up to 10 days), cup coral exhibited significant reductions in survival at exposures of 200 mg/L and significant tissue loss at exposures of 0.02 mg/L. Raimondi et al. (1997) could not determine whether the response was due to physical or chemical effects. Survival and tissue loss responses in the cup coral, however, do support observations by Hyland et al., (1994) of changes in abundance of sessile epifauna affected by drill mud discharges.

4.1.3 Long-Term Mortality Studies

Long-term mortality studies have been conducted principally on organisms from the Gulf of Mexico. Neff et al. (1980) exposed Coquina clams (*Donax variablis*) to the suspended particulate phases of a spud fluid and medium and high density lignosulfonate drilling fluids for two, three, four, and eight days. No mortality resulted from exposures to the spud mud. The medium and high density fluids produced decreasing LC50 values with time (49,000 ppm [48 hr] to 20,000 ppm [192 hr] and 95,000 ppm [48 hr) to 41,000 ppm [192 hr], respectively). Conklin et al. (1980) conducted life cycle toxicity tests on the mysid (*Mysidopsis bahia*). LC50 values decreased with time, ranging from 161 ppm after four days to 50 ppm after 42 days. Neff et al. (1981) performed chronic tests on the polychaetes *Ophryotrocha labronica* and *Ctenodrilus serratus* using the aqueous fraction (MAF) and filtered fraction (FMAF) of a seawater-chrome lignosulfonate drilling fluid. The 16 day LC50 for both fractions exceeded 100,000 ppm on *O. labronica*, while the 20 day LC50 for C. serratus was 13,000 ppm for MAF and 15,000 ppm FMAF, respectively.

Based on the results of these studies, the chronic toxicity of drill muds appears to vary as a function of time and corresponding acute toxicity (Petrazuollo, 1983). This relationship may overestimate acute versus chronic toxicity values since it can not take into account reversibility of toxicant effects or compensatory capacity of an organism. However, Petrazuollo concludes that chronic lethal toxicity values will generally lie within an order of magnitude of the 96-hour LC50 values.

4.1.4 Long-Term Sublethal Effects Studies

Long-term studies have focused on two primary types of responses. The first is the effect of drill muds on behavior, reproduction, growth/development, physiological/biochemical activities, and histopathology. Much of this information is from early studies using chromium or ferrochrome lignosulfonate muds or muds containing diesel additives. These study results should not be extrapolated to generic mud types presently permitted for use on OCS drilling operations. The other major area of focus has been metal accumulation in organism tissues.

Laboratory studies on community recruitment and development of benthic macro and meiofauna have been performed using whole muds or barite mixed with sediments or applied in a layer over sediments. These experiments ranged from 8-10 weeks in length (Cantelmo et al., 1979; Tagatz et al., 1978; Tagatz and Tobia, 1978). Polychaetes exhibited the most significant changes in abundance related to concentrations of drill mud sediment mixtures and layered muds; similar sensitivity was noted as a result of exposure to barite. Coelenterate abundance was significantly reduced from exposure to both the mud mixture and the mud layer. Unlike the annelids, however, the coelenterate reductions were not concentration-dependent. Arthropods reacted only to the drill mud layer over sediment. Molluscs did not appear to be significantly affected by the drilling fluid applications but were affected by a barite covering. Exposure to the barite sediment mixture increased nematode abundance and total meiofaunal density while a barite layer over sediment reduced meiofaunal density and abundance of nematodes.

Effects of drill mud discharges on epifauna of hard-bottom substrates was examined as part of the MMS studies of drilling operations off Point Arguello, CA (Hyland et al., 1994). Epifaunal abundance and composition were measured in low- and high-relief habitats and related to drill mud settling fluxes to determine if impacts from Platform Hildago discharges were occurring. Of the 22 taxa evaluated, four displayed significant time/dose changes in abundance that suggested effects associated with the drilling operations (i.e., abundance decreased both during the drilling operation and relative proximity to the discharge). These taxa included the following:

- sabellid polychaetes in low-relief habitat;
- *Caryophyllia spp.* (ahermatypic coral) in deep low-relief and deep high-relief habitat;
- galatheid crabs in deep low-relief habitat; and
- *Halocynthia higendorfi igaboja* (ascidian) in deep low-relief habitat.

All but galatheid crabs are suspension feeders and sessile, and they cannot escape solids settling and accumulation. As such, the authors proposed that reductions in abundance were associated with physical effects of increased particle loading and that variations in faunal abundance was not due to chemical components of discharged drill mud. As noted in Section 3, barium was the only compound to show elevated concentrations in suspended or surficial sediments. The barium is in the biologically inert form of barium sulfate and considered insoluble and essentially non-toxic.

Another study examined hard-bottom epifauna following exploration drilling in the Santa Barbara Channel (Nekton, Inc., 1987). Elevated concentrations of barium were observed in sediment traps and surficial sediments within 500 m of the discharge. Sediment concentrations remained elevated within 200 m of the discharge for at least one year after cessation of drilling. However, abundances of hard-bottom epifauna did not change significantly between pre- and post-drilling surveys.

4.1.6 Bioaccumulation of Metals from Drilling Fluids

Drill muds and cutting are primary sources for several metals associated with drilling-related discharges. Potentials for accumulation of metals in biota at levels that may become toxic to the organism or higher trophic levels are an issue of concern in the assessment of oil and gas impacts.

Numerous field studies suggest that enrichment of certain metals may occur in surface sediments around platforms (Tillery and Thomas, 1980; Mariani et al., 1980; Crippen et al., 1980; and others). In a review of these studies, Petrazuollo (1983), noted that enrichment of metals in sediments attributable to drilling activities was generally limited to areas within 300-500 m of the platform, and concentrations decreased with distance from the platform. Maximum enrichment factors seldom exceeded ten.

Concentrations of metals required to produce physiological or behavioral changes in organisms vary widely and are determined by factors such as the physiochemical characteristics of the water and sediments, the biochemical form of the metal, and the organism's size, physiological characteristics, and feeding adaptations. Metals are accumulated at different rates and to different concentrations depending on the tissue or organ involved. Laboratory studies on metal accumulation as a result of exposures to drill muds have been conducted by Tornberg et al. (1980), Brannon and Rao (1979), Page et al. (1980), McCulloch et al. (1980), Liss et al. (1980) and others. Results from these laboratory studies are summarized in Table 4.3. Enrichment factors were generally low (<10) with the exception of barium and chromium with maximum enrichment factors of 300 and 36, respectively.

Depuration studies conducted by Brannon and Rao (1979), McCulloch et al. (1980), and Liss et al. (1980) as part of the studies described above have shown that organisms tested have the ability to depurate some metals when removed from the exposure. In various tests, animals were exposed to drill muds from 4-28 days, followed by a 1-14 day depuration period. Uptake and depuration of barium, chromium, lead, and stontium were monitored and showed a 40-90% decrease in excess metal concentrations in tissues following the depuration period. Longer exposure periods generally meant a slower rate of loss of the metal. In addition, release of the excess metal was slowed if uptake was through food rather than from solution.

Jenkins et al. (1989) conducted studies of barium uptake in organisms exposed to drill muds from operations in central California. The results indicated uptake of barium by exposed organisms; however, the barium was present in tissue cells as discrete barium sulfate particles and not as a constituent of the tissue matrix. Further, the organisms were capable of subsequently eliminating the ingested barium sulfate.

Table 4.3 Metal Enrichment Factors (Ers) in Shrimp, Clams, Oysters and Scallops Following Exposure to Drill Muds and Drill Mud Components (Adapted from Petrazuollo, 1983). Er = Concentration in Exposed/concentration in Controls.

Test Organism	Test Substance (ppm)	Exposure Period (days)	ER Ba	ER Cr	ER Pb	ER Sr	ER Zn
Paleomonetes pugio[a]	Barite						
whole animal	5	7	150			1.3	
-	50	7	350			1.9	
-	5	7	2.2[b]			1.8	
-	50	7	29[b]			2.2	
carapace	500	8, post	7.7			1.2-2.5	
hepatopancreas	500	ecdysis	13			1.9-2.8	
abdominal muscle	500	8	12			1.5-2.8	
carapace	500	106	60-100			1.6-7.4	
hepatopancreas	500	106	70-300			0.03	
abdominal muscle	500	106	50-120			0.71	
Rangia cuneata[c] soft tissue	12.7 lb/gal lignosufonate (50,000 MAF)	4-static		1.-1.4	1.2-1.7		
	13.4 lb/gal lignosulfonate (100,000 MAF)	16-static		1.6-2.5			
	Layered solid phase	4-daily renewal		4.3			
Crassostrea gigas[c] soft tissue	9.2 lb/gal spud fluid (40,000 MAF)	10 static			2.1		1.1
	10,000 SPP	4 daily		2.5			
	20,000 SPP	renewal		3.0			
	40,000 SPP	4		3.0			
	60,000 SPP	4		5.5			
	80,000 SPP	4		7.4			
	12.7 lb/gal lignosuldonate (40,000 MAF)	10 static			2.3		1.4
	20,000 MAF	14		2.9			
	40,000 MAF	14		3.9			
	10,000 SPP	daily		2.2			
	20,000 SPP	renewal		4.4			
	40,000 SPP	14		8.6			
	60,000 SPP	14		24			
	80,000 SPP	14		36			
	17.4 lb/gal lignosulfonate (40,000 MAF)	10 static			0.56		1.0
	20,000 MAF	14		2.1			
	40,000 MAF	14		2.2			
Placopecten magellanicus[d] kidney	uncirculated lignosulfonate 1,000	28	8.8	2.6			

adductor muscle	1,000 low density lignosulfonate	28	10	1.2			
kidney	1,000	14 27		1.6 2.1			
adductor muscle	1,000	14 27		2 2			
	FCLS 30	14		3.2-5.7			
	100	14		5.2-6.0			
	1,000	14		6.0-7.2			

a Brannon and Rao, 1979.
b Levels following a 14-day deputation period.
c McCulloch, et al., 1980
d Liss et al., 1980.

Studies of metal accumulation in tissues of bottom-dwelling organisms exposed to drill mud discharges were conducted as part of the long-term monitoring of platform operations in Santa Maria Basin (Steinhauer and Imamura. 1993). Results of tissue analyses were highly variable. However, barium concentrations in tissues of a sea slug (*Pleurobranchaea sp.*) occasionally appeared to be elevated, whereas, concentrations of chromium, mercury, and lead did not exhibit any discernable patterns related to drilling operations. Studies of contaminant bioaccumulation associated with exploratory drilling operations performed as part of the Georges Bank Monitoring program (Phillips et al., 1987) did not observe any significant uptake or accumulation of drill muds constituents (metals and hydrocarbons) in tissues of a bottom-dwelling bivalve (*Arctica islandica*). Similarly, the GOOMEX study in the Gulf of Mexico (MMS, 1995) did not detect any significant bioaccumulation of metals in invertebrates or fish around production platforms.

4.1.7 Summary of Water-Based Drilling Fluid Impacts

EPA (1999), in its assessment of proposed effluent limitations and standards for synthetic-based drilling fluids (SBF), summarized the existing literature of field observations of environmental impacts from water-based drill mud discharges. The review concludes that drilling-related discharges are capable of producing localized impacts. such as increased sediment barium concentrations, but plume dispersion is considered sufficient to minimize water quality or water column toxicity impacts in open marine waters of the OCS.

Drill mud impacts identified in this review are of two distinct types: (1) effects due to burial by drill muds and/or cuttings; and (2) long-term effects due to chemical contamination and/or physical alteration of sediments. In the first case, deposition of cuttings adjacent to the discharge point is most common in deep water locations, and infaunal abundance are expected to decrease in and around cuttings piles. Generally, studies have not been designed to discriminate whether observed effects were due to chemical or physical effects.

The most commonly observed chemical alteration of sediments associated with drill mud discharges was increased barium concentrations. Generally, sediment barium levels decrease logarithmically with distance from the discharge and a drill mud footprint is more limited spatially in deeper water depths than in shallower waters. Background levels of barium generally are reached within a few kilometers or less from the discharge, depending on water depth.

In spite of the potentially broad distribution of barium, biological effects typically are only observed at distances within 0.5 km of the discharge. Although some evidence for metal bioaccumulation from drill mud exists, the magnitude of bioaccumulation is low (e.g., usually less than a factor of five; EPA, 1999).

4.2 Produced Water

Waters associated with oil and gas producing formations are extracted with the petroleum, subsequently treated, and then discharged or reinjected into the formation. The composition of produced waters is described in Section 2.3 of this report.

4.2.1 Toxicity of Produced Water

Rose and Ward (1981) reported the results of bioassay tests conducted on brown and white shrimp, barnacles, and crested blennies exposed to varying concentrations of produced water from the Buccaneer Field in Texas. Four series of tests were performed on these organisms; results are shown in Table 4.5. Crested blennies were the least sensitive of the organisms tested, while the white shrimp was most sensitive. The oxygen demand of the produced water did not appear to dramatically affect the outcome of the tests.

Armstrong et al. (1979) investigated the effects of oil field brine effluent on benthic communities in Trinity Bay, Texas. Contaminants of concern in this study were naphthalenes in sediments and overlying water column. Their results indicated that in this shallow (2-3 m) warm water bay there was a paucity of benthic organisms within 150 m of the platform. At distances from 150 m to 200 m, numbers of species and individuals increased and, beyond that, community measures were comparable to those at control stations. Because of the shallow water depth, and the discharge of effluent only 1 m from the bottom, this study has limited applicability to deeper environments but may represent a worst-case situation.

Table 4.5 Median lethal concentrations (LC50's) for organisms exposed to produced water (Rose and Ward, 1981).

Test Organism	LC50 (ppm)
Brown Shrimp	
Larva	8,000-12,000
Subadult	44,000-183,000
Adult	78,000-178,000
White Shrimp	
Subadult	66,000-133,000
Adult	37,000-92,000
Barnacle	8,000-154,000
Crested Blenny	7,000-408,000

A series of studies (Higashi and Crosby, 1994; Cherr and Fan, 1996, 1997; Higashi and Jones, 1997) evaluated the effects of produced water discharges, and especially the bioavailability of soluble barium, at a shallow-water site near Santa Barbara on toxicity, sublethal effects, and bioaccumulation. Using a tiered toxicant characterization approach, Higashi and Crosby (1994) determined that the majority of toxicity to mussel embryos was associated with the "divalent cation" fraction of the produced waters. In contrast, response observed with sea urchin sperm toxicity tests were associated with polar organic substances. Analyses of the chemical compositions of the produced waters indicated that barium concentrations were approximately three orders of magnitude higher than those in seawater. Although little is known about the toxicity of divalent cations, previous studies (Vicent et al., 1986) had noted that barium at levels found in produced water can exert toxic effects to amphipods. Subsequent, related studies (Cherr and Fan, 1996) indicated that soluble barium (as barium acetate) at concentrations of 0.2-0.9 mg/L exhibited teratogenicity to mussel embryos. Higher concentrations were associated with decreased toxicity, possibly due to precipitation of barium from seawater in an insoluble form (e.g., barium sulfate). Adverse effects to mussel embryos exposed to produced water include abnormal shell calcification and embryo morphology. Further, barium concentrations in shells of adult mussels appeared to be inversely correlated with distance from the site of the produced water discharge. Related studies also indicated a complex response by diatoms to exposures to produced waters. Produced water exposures appeared to be stimulatory to production of concentrations of 0.028 mg/L but inhibitory at concentrations of 0.113 mg/L; effects diminished at relatively higher concentrations, possible due to barium precipitation from seawater. In total, these studies indicate that soluble barium in produced water may be bioavailable, with potentials for sublethal effects at relatively low concentrations. These results were consistent with observations at the same produced water discharge site of reduced settling rates by red abalone larvae (Raimondi and Schmitt, 1992), reduced reproductive fertilization in purple sea urchins (Krause, 1993), and decreased growth rates, along with declines in general condition and tissue production in mussels (Osenberg et al., 1992).

While these studies indicate that produced water discharges exhibit potentials for sublethal effects to marine organisms at a shallow-water site, the magnitude of comparable effects at OCS locations is expected to be insignificant. As mentioned, produced waters are discharged from OCS platforms at least 10 m below the surface, and the discharge plume is expected to be diluted rapidly with distance from the platform and typically confined within a relatively small depth range (due to water column density trapping). Thus, only planktonic, nektonic, and attached fouling organisms within limited depth range and distances from the discharge would be exposed to produced water constituents at levels potentially causing adverse impacts. Planktonic organisms do not rely on the platforms for habitat, and the spatial scale of potential impacts to planktonic organisms from OCS produced water discharges is negligible compared to the total size of the habitat. A proportionately larger fraction of the fouling community present on the platform may be exposed to produced ware discharges. However, these organisms are dependent on the platform rig as a reef substrate and do not represent natural or spatially-limited communities. Mussels are harvested from several OCS platforms, including those with active produced water discharges, and sold commercially for human consumption. In this sense, the produced water discharges have not caused obvious reductions in the productivity of the fouling communities. Similarly, OCS platforms typically support high abundance of fish assemblages. There is no present evidence from studies of Pacific OCS or Gulf of Mexico platforms that produced water discharges affect abundances or health of resident fish.

As part of his review of produced waters in the Santa Barbara Channel off California, Neff (1997) summarized the potential for environmental effects from the following produced water constituents: arsenic; barium; cadmium; mercury; phenols, BTEX compounds; and PAH compounds. A synopsis of that analysis is presented below.

Arsenic

Arsenic concentrations in produced water generally are low, but in some instances can be up to 30 times higher than that in ambient seawater (1.5 to 3.0 ug/L). Dilution of only five-fold would decrease these concentrations in the receiving water below the marine chronic water quality criterion. Two studies of arsenic bioaccumulation in bivalves and fish in the Gulf of Mexico indicated that this metal is not accumulated above concentration ranges representative of background conditions.

Barium

Barium concentrations in produced water are high relative to that in seawater (>1,000 times). Initial mixing of the produced water with sulfate-rich seawater not only rapidly dilutes these high barium concentrations but also promotes precipitation of dissolved barium as barite, which has an extremely low solubility in sea water (ca. 50 ug/L). Tissue concentrations of barium in soft tissues in fish and bivalves adjacent to produced water discharges in the Gulf of Mexico were not different from those from reference site.

Cadmium

Concentrations of cadmium in offshore California produced waters can reach 15 ug/L, which is between one and two orders of magnitude above background seawater levels. A 750 to 1,000 fold dilution would reduce these produced water concentrations to background concentrations. Nevertheless, produced water cadmium levels are always below the acute water quality criterion of 43 ug/L and usually below the chronic criterion of 9 ug/L. Studies in the Gulf of Mexico indicated that organisms exposed to produced waters did not accumulate cadmium compared to background conditions.

Mercury

Mercury, predominately in the inorganic form, occurs in very low concentrations in produced waters of offshore California, yet it may be 20-50 times higher than that of seawater. Mercury in produced waters will be diluted rapidly in the receiving water to background levels. There was no evidence from Gulf of Mexico studies of mercury bioaccumulation in marine organisms exposed to produced waters.

Phenols

Phenols and alkylated homologs in produced waters are diluted rapidly upon discharge. Photodegradation and microbial degradation also remove these compounds from the water column at a rate as high as 5 percent/hour. There was no indication that phenol was bioaccumulated from produced waters in the Gulf of Mexico.

BTEX

BTEX compounds may be present at high concentrations (10,000 ug/L) in produced waters. However, these compounds are diluted very rapidly such that exceedences of water quality criteria are not expected for BTEX compounds in receiving waters near produced water discharges. Bioaccumulation of BTEX compounds in tissues of marine organisms to levels that represent a human health risk also are not expected because these compounds have very low partitioning coefficients and bioconcentration factors (i.e., affinities for uptake and accumulation by organisms).

PAHs

PAH concentrations up to 26 ug/L have been observed in produced waters from California OCS operations. This concentration is very low compared with PAH levels in produced water observed in the Gulf of Mexico. Initial dilution of the produced water plume will reduce PAH concentrations below those potentially harmful to marine life. Evidence exists of low-level PAH accumulation in organisms exposed to produced waters in the Gulf of Mexico. These observations did not indicate that accumulation of PAHs was deleterious to the receptor organisms or that they represented the potential for biomagnification in the food chain to harmful levels.

4.2.2 Bioaccumulation Potential of Produced Water Constituents

Continental Shelf Associates (1997) recently completed a study to (1) determine whether statistically significant bioaccumulation of chemical contaminants occurs in edible tissues of resident fishes and invertebrates at offshore platforms in the Gulf of Mexico and (2) evaluate the ecological and human health implications of observed contaminant concentrations in tissues or organisms collected from the platforms. No bioaccumulation from produced waters of mercury, a phthalate ester, or the PAHs fluorene and benzo(a)purene was evident. The evidence for bioaccumulation from produced water exposures of arsenic, barium, cadmium, radium isotopes, phenol, and total PAHs was weak, inconclusive, or contradictory. Further, the study indicated that none of the EPA-specified target compounds were present in edible tissues of fish and invertebrates at concentrations that would be considered harmful to the organisms or represent a potential health risk to consumers. Neff (1997b) concluded that the results from these studies in the Gulf of Mexico would be relevant and applicable to conditions in the California OCS. Accordingly, produced water discharges do not appear to represent a significant risk to marine organisms or their consumers from chemical bioaccumulation.

Natural and transplanted mussels have been collected and tested as sentinal organisms for ongoing statewide and national water quality monitoring programs (i.e., Mussel Watch Program). Mussels are used because they filter water and concentrate contaminants present in seawater. In this way, contaminant concentrations in mussels tissues reflect the quality of ambient waters. Mussels have been harvested commercially off of platforms in the Southern California OCS for more than one decade. These mussels are tested for tissue contaminants, and the results consistently demonstrate that the mussels are suitable for human consumption (R.Meek, ECOMAR, pers. comm.). This suggests indirectly that platform discharges do not typically cause contaminant bioaccumulation in mussels growing on platforms.

4.3 Minor Discharges

The total volume of proposed treated sewage discharges is small in relation to the volume of the receiving water. Further, these discharges are expected to be rapidly diluted as they are discharged into open water with average currents ranging from 5-25 cm/s. Consequently, any impact typically associated with sanitary discharges, such as oxygen demand or effects from chlorine, are expected to be negligible.

Discharges of desalinization brines, a byproduct of the generation of fresh water, should also have minimal impact. This discharge is expected to be rapidly diluted to ambient salinity, and any impact such as osmotic stress would exist only at the point of discharge. Studies of the effects of a natural brine seep at the East Flower Garden Bank in the Gulf of Mexico (Bright et al., 1980) indicated that oxic hypersaline systems can be very productive and diverse, possibly increasing ambient food supplies which may have a greater effect than the salinity stress inflicted on the immediate area.

During the exploration phase, blow-out prevention fluids may be used to control well pressures. Discharges of such fluids are intermittent; the contents of these fluids include ethylene glycol and water, both of which should produce no significant effects to the ambient biota. Cooling waters, degreased ballast water, bilge waters and deck drainage may also be discharged with little or no impact to the marine environment.

5. BIOLOGICAL COMMUNITIES AND ECOSYSTEMS

5.1 Overview

The area encompassed by this proposed NPDES permit extends from the Santa Maria Basin in the north, southward through the upper part of the Southern California Bight to the San Pedro Channel (Figure 1.1). This area includes a highly complex submarine topography with water depths ranging from about 30 m to about 300-400 m (corresponding to, thus providing a multitude of habitats for many marine organisms. The area south of Point Conception has been well documented in a series of studies over the last 40 years; the area north of Point Conception has been the subject of studies conducted by MMS as part of the oil and gas exploration environmental studies program. Important references that summarize much of the information and data within the permit region include Dailey et al. (1993), Bakus (1989), SLC (2000), and SAIC and MEC (1995). These references among others are used extensively in characterizing the biological communities and ecosystems described in this section.

Numerous physical factors play a major role in the development of structure and diversity of the marine communities of the permit area. Submarine topography, currents, upwelling, and water temperatures are among these factors. Point Conception and the northern Channel Islands are generally considered to be the boundary zone between warmer and colder waters in California. Several water masses meet in this area and the upwelling that results provides important nutrients for primary production. Because of the changes in the physical oceanographic regime north and south of Point Conception, differences are seen in the makeup of some marine communities, although these changes are less pronounced in deeper areas (e.g., greater than 200 m bottom depths), and many deeper-dwelling species have geographic distributions that extend to at least northern California (e.g., Lissner et al., 1991). For shallow-water invertebrates in particular, a number of species reach the northern or southern limits of their distribution or breeding range near Point Conception.

The importance of the commercial fisheries in southern California is known worldwide. The diverse food base supporting commercial fisheries includes zooplankton and various benthic invertebrate species. The permit area is also utilized by large numbers of marine mammals and seabirds, including several endangered species.

Important habitats in the permit area include the Channel Islands, representing haulout and pupping areas for pinnipeds and rookeries for seabirds. Whales and dolphins also occur throughout the general region. Some hard bottom areas and associated fish and invertebrate communities of the continental shelf are important because they are less common than soft-bottom habitats that comprise the vast majority of substrate types and some organisms, particularly in high-relief areas, are more sensitive to disturbance from suspended particles and sediment burial that can result from some types of discharges. Further, the size and value of the commercial fishery in the permit region makes the fishing areas in the Santa Barbara Channel, including the Channel Islands, important habitats

5.2 Phytoplankton

5.2.1 Important Species and Groups

The term "phytoplankton' refers to all the free floating unicellular organisms that produce organic matter by photosynthesis. In marine waters such as the permit region, the principal members of the phytoplankton are diatoms (Chrysophyta) and dinoflagellates (Pyrrophyta). Diatoms are nearly always the dominant form, except during periods of "red tide" when dinoflagellate species predominate. Among the diatoms, the genus *Chaetoceros* is generally the most abundant (Hardy, 1993; Eppley, 1986; Bolin and Abbott, 1963).

Because phytoplankton passively drift with the currents, most species found in the Southern California Bight are widely distributed and typical of the entire California Current system. Most are temperate species found along the entire west coast and in many of the world's oceans. There have been numerous taxonomic studies of the southern California coastal phytoplankton (Briand, 1976; Kofoid & Swezy, 1921; Cupp, 1943; Reid et al., 1970). From these and other studies, hundreds of phytoplankton species have been identified; however, only a few species are numerically dominant. Within this subset, different species may be dominant at different times of the year in direct response to successional changes and advection. (Sautter and Sancetta, 1992; Allen, 1928, 1936; Briand, 1976). Table 5.1 summarizes the numerically dominant phytoplankton species identified in five studies: three studies in southern California (Eppley, 1986; Allen, 1936; Briand, 1976) and two studies in central California (Garrison, 1979; Schrader, 1981). Considering that these studies ranged from one year (Briand, 1976) to 10 years in duration (Allen, 1936) and from southern to central California, the results are comparable with regard to dominant species.

5.2.2 Distribution, Abundance and Temporal Variability

The distribution and abundance of phytoplankton within the permit area largely reflect physical processes and hydrographic events in the California Current system (Hardy, 1993). Seasonal cycles of productivity and species composition are similar to those found in other areas of the California coast (Sautter and Sancetta, 1992; Bolin and Abbott, 1963). Productivity is largely controlled by the frequency and intensity of upwelling events. Seasonal changes in species composition within the Bight result from species succession, and advection of species by the current system. The southward flowing California Current introduces cold water species from the subarctic Pacific and the countercurrent flowing from the south introduces species typical of warmer waters.

In general, upwelling is an important source of nutrients to the euphotic zone and largely determines the productivity of the region. Areas of upwelling are three times as productive for phytoplankton as the coastal zone and six times as productive as the open ocean. In the Southern California Bight, upwelling is a dominant hydrographic feature and consequently, productivity is high (Hardy, 1993). Smith and Eppley (1982) estimated quarterly and average annual primary production for the Southern California Bight covering a period from 1920 through 1979. Average annual production was 392mg C/m^2/dy or 143g C/m^2/yr. Maximum production nearly always occurred in the spring with minimum production during the winter, corresponding with periods of maximum and minimum upwelling activity, respectively. As shown in Figure 5.1, there may be significant annual variation in primary productivity with up to threefold differences between years.

Table 5.1 Numerically Dominant Phytoplankton Species from the California Current System

Reference	Species	Comments
	Diatoms	
1,2,3,4	*Asterionella japonica*	Neritic, south temperate
1,5	*Bacteriastrum hyalinum*	Neritic, widespread .
1	*Chaetoceros compressus*	Neritic, boreal to south temperate
3,4	*C. constrictus*	Neritic, north temperate
1,4,5	*C. costatus*	Neritic, warm water
1,2,4.	*C. curvisetus*	Neritic, south temperate
1,3,4,5	*C. debilis, C. radicans*	Neritic, north temperate
1,5	*C. socialis*	Neritic, north temperate
3	*C. vanheurcki*	Neritic
1	*Dactyliosolen mediterraneus*	Neritic, widespread
1,3,4,5	*Eucampia zoodiacus*	Neritic, south temperate
1,5	*Hemiaulus hauckii*	Oceanic or neritic, temperate-tropical
1,5	*Leptocylindros danicus*	Neritic, north temperate
3,4	*Nitzschia pacifica*	Neritic or oceanic, temperate
3,4	*N. pungens*	Neritic or temperate
1,3,4,5	*N. seriata*	Neritic, north temperate-arctic
1,2,5	*Rhizosolenia delicatula*	Neritic, temperate
1,2,3,4,5	*Skeletonema costatum*	Neritic, cosmopolitan
1,4,5	*Thalassionema nitzschioides*	Neritic, north temperate
3,4	*Thalassiosira aestivalis*	Neritic
1,4,5	*T. decipiens*	Neritic, north temperate
1,5	*Thalassiothrix frauenfeldii*	Oceanic, south temperate, widespread
	Dinoflagellates	
1,2,5	*Ceratium furca*	
1,2,4,5	*Gonyaulax polyedra*	Important "Red Tide" species
1,2,5	*Gymnodium simplex*	
4,5	*G. splendens*	
4	*Peridinium trochoideum*	Neritic, often estuarine
1,2,5	*Prorocentrum micans*	

Source: Allen (1936)[1]; Briand (1976)[2]; Garrison (1979)[3]; Schrader (1981)[4]; Eppley [5].

During periods of upwelling, plankton is more uniformly mixed in the upper water layers (Hardy, 1993). In the absence of upwelling, Eppley et al. (1970) demonstrated that the maximum phytoplankton density occurs in the thermocline and in the upper portion of the nutricline (layer of separation between high and low nutrients), usually at depths corresponding to 3 to 30% of surface irradiance. Owen (1974) summarized chlorophyll a values (an index of phytoplankton biomass) for the region on a quarterly basis during 1969. Phytoplankton biomass was high near the coast and decreased offshore. This distribution is largely in response to elevated surface nutrients near shore, resulting from upwelling. The seasonal distribution is apparent with greatest phytoplankton biomass occurring during spring and summer and lower levels during fall and winter.

The presence of eddies within the Southern California Bight has important affects on the distribution and abundance of phytoplankton (Hardy, 1993). Surface flow within the Bight is dominated by a semipermanent cyclonic gyre driven by the California Current on the west and augmented by the coastal countercurrent on the east. A characteristic of such eddies is that the thermocline rises near the center, forming a dome that displaces surface mixed layer water with nutrient-rich water from below, enhancing primary productivity (Owen, 1980). Enhanced productivity also occurs in the eddies formed in the wake of islands in the Bight.

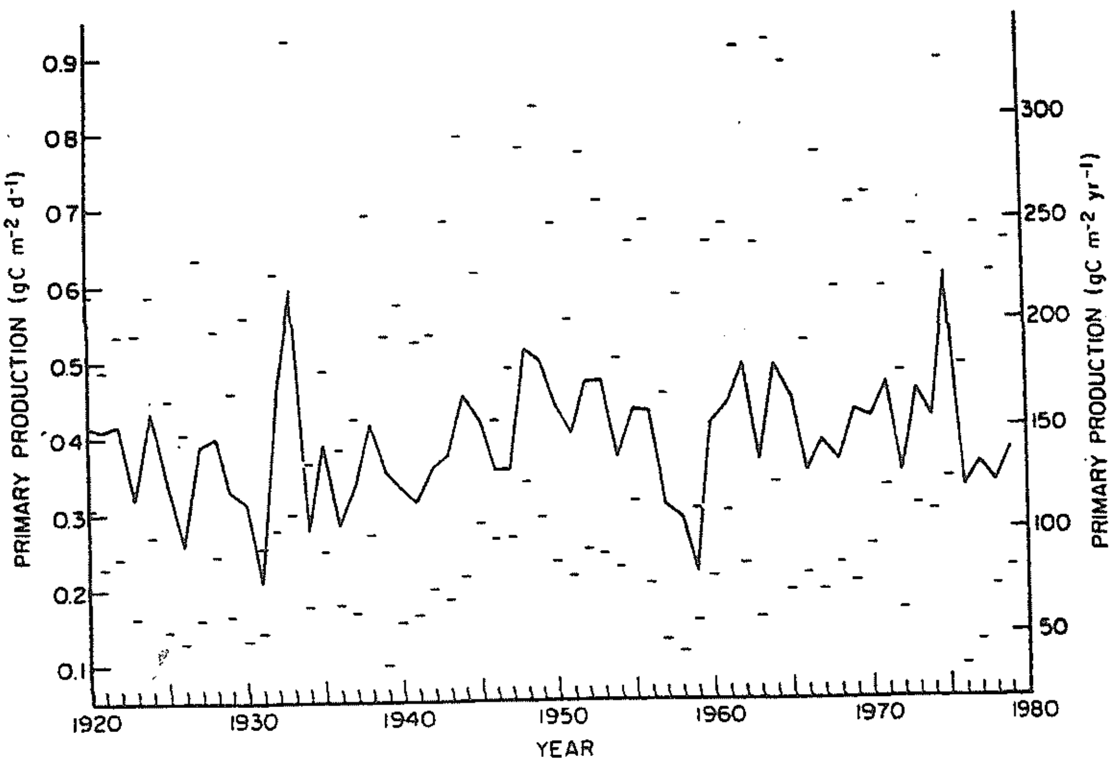


Figure 5.1

ESTIMATED ANNUAL PRIMARY PRODUCTION IN THE SOUTHERN CALIFORNIA BIGHT, 1920-1979. DASHED LINES INDICATE RANGE OF SEASONAL PRODUCTION RATES FOR EACH YEAR (form Smith and Eppley, 1982).

Seasonal variations in phytoplankton were described by Briand (1976) for the area near Seal Beach and may be considered typical of the Southern California Bight, and consistent with information summarized by Hardy (1993). Variations in cell numbers and volumes are summarized in Figure 5.2. The yearly average standing crop was dominated by diatoms (64%) on the basis of cell numbers and by dinoflagellates (79%) on the basis of cell volume. The only two months during which dinoflagellates were prevalent in cell numbers were August, when a red tide bloom developed, and October when phytoplankton taxa were fairly evenly distributed between diatoms and the other groups such as microflagellates. Diatoms dominated phytoplankton volume during the period from January to April. The representatives of other groups were most abundant from October to January, when they accounted for approximately one-third of the total cell counts. Due to their relatively small volume, they never represented more than 6.5% of the total phytoplankton volume.

The relative importance of nannoplankton (less than 20 um diameter.) and net plankton (greater than 20 um diameter.) in the California Current System has been investigated by Malone (1971), Garrison (1976) and Beers et al. (1980). Nannoplankton accounted for 60 to 99% of the observed productivity and standing crops. Nannoplankton, once thought to be relatively stable throughout the year (Malone, 1971), are now believed to show considerable spatial and temporal variability in biomass (Beers et al., 1980). Net plankton standing crop and productivity increased substantially during periods of upwelling. Both fractions showed seasonal changes; the net plankton concentrations increased dramatically during periods of upwelling while nannoplankton concentrations were decreased.

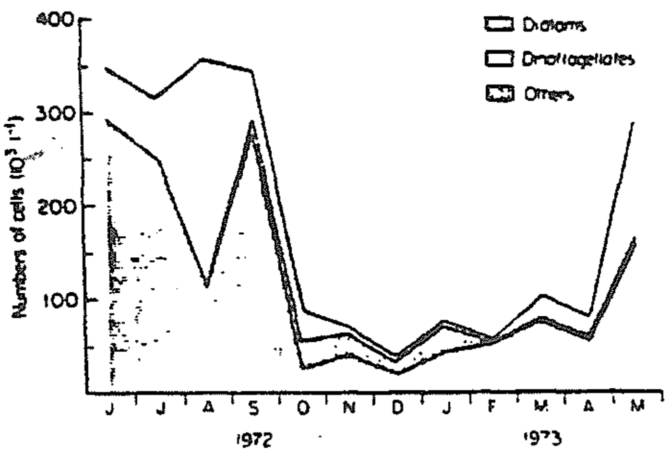


Figure 5.2a

THE MONTHLY VARIATIONS IN THE NUMBERS OF CELLS OF DIFFERENT KINDS

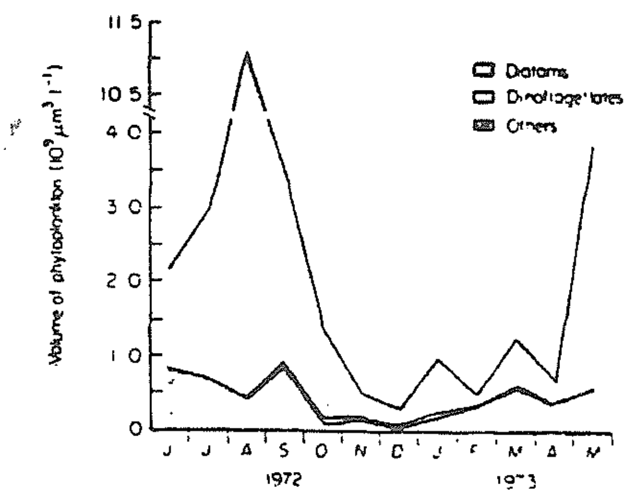


Figure 5.2b

THE MONTHLY VARIATIONS IN THE VOLUMES OF THE CELLS OF DIFFERENT KINDS

5.3 Zooplankton

5.3.1 Important Species and Groups

Zooplankton form a taxonomically diverse assemblage of organisms including members from every major animal phylum. As a group, zooplankton are characterized as possessing only limited swimming ability and therefore drift passively with the currents. Zooplankton are divided into two major components: holoplankton, which are permanent members of the plankton, and meroplankton, which are planktonic for only part of their life cycle. The latter group includes larval forms of many fish (ichthyoplankton), and invertebrate species. In the Southern California Bight, larvae of the commercially and ecologically important northern anchovy *Engraulis mordax* are a significant component of the plankton community (Moser and Pommeranz, 1999; McGowan and Miller, 1980).

The Southern California Bight is characterized as an area of converging water masses with water originating in the Subarctic Pacific, the Eastern Central Pacific and the Equatorial Pacific. As a result of the admixture of these waters, the zooplankton off southern California reflects transitional fauna characteristics (Dawson and Pieper, 1993). Zooplankton include Bight endemics (larval fish and invertebrates), as well as the fringes of large populations located in adjacent water masses that are characteristic of northern and southern regions. As a result, there is a heterogeneous assemblage of species, both in the epipelagic zone (Kleppel et al., 1982; McGowan, 1968, 1971) and in the meso- and bathypelagic zones (Ebeling et al., 1970).

Much of the zooplankton data off Southern California has come from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program initiated in 1979 (Dawson and Pieper, 1993). A summary of the common organisms and remarks about their distribution is presented in Table 5.2. Ahlstrom (1965, 1969) summarized information on CalCOFI collections of fish eggs and larvae in the California Current System. Twelve larval types (species and genus) comprised over 90% of all larvae collected (Table 5.3). The northern anchovy *(Engraulis mordax)* and Pacific hake *Merluccius productus* represented 40-60% of their collection. Moser and Pommeranz (1999) studied fish larvae commonly collected in surface, shallow, and deep water tows in the Southern California Bight (Table 5.3A). Northern anchovy represented approximately 95% of the total combined sampling effort.

Table 5.2 Zooplankton Taxa of the Southern California Bight (from Seapy, 1974).

Major Taxon	Common Species	Distribution Remarks
Coelenterates (Cnidaria)	Poorly known for the area.	
Ctenophores	*Pluerobrachia bachei*	Common in nearshore plankton.
	Beroe sp.	Reported from south of the area. Densities of less than 50/10,000 m^3 of water in the upper 110m.
Chaetognaths	*Sagitta euneritica, S. bierii, S. minima,S. inflata*	No seasonality pattern or inshore-offshore difference in abundance.
Polychaetes	*Vanadis formosa*	Offshore distribution (200 km).
	Torrea candida	
	Tomopteris elegans	Can be extremely abundant.
	Travisiopsis lobifera	Cold water form.
Mollusks		
-Pteropods	*Limacina helicina*	
-Heteropods	*Atlanta peroni, Atlanta sp., Carinaria japonica*	
-Cephalopods	*Abraliopsis felis, Gonatus onyx*	
Crustaceans		
-Copepods	*Libinocera trispinosa*	Dominant in surface samples in Santa Barbara Channel. Maximum abundance in November (McGinnis, 1997).
	Acartia tonsa	
	A. clausi	Abundant in summer months.
	Calanus helgolandious	All stages abundant in May-June.
	Rhinpcalanus nasutus	Juveniles abundant in July-August. Adults abundant in May-June.
	Oithona similis	Most abundant cyclopoid copepod from samples off Scripps.
-Amphipods	*Vibilia armata*	Captured at surface at night, at 200 m in the day.
-Cladocera	*Penila avirostris*	Maximally abundant in December, 1969 in Santa Barbara Channel (McGinnis, 1971).
	Evadne nordmanni, Podon ployphemoides, E.spinifera, E. tergestina	Abundant in July-August, 1968 in nearshore waters off La Jolla.
-Euphausids	*Euphausia pacifica, Nematoscelis difficilis, Nyctiphanes simplex Stylocheiron longicorne, Thysanoessa gregaria, T. spinifera*	Listed in order of abundance over Southern California Bight.
	Sergestes similis	
-Decapods	*Doliolum denticulatum*	Recorded from 650 m trawls.
	D. genbuari	
Thaliacea	*Cyclosalpa bakeii*	Abundant in nearshore waters in summer.
	Pega confoederata,Salpa fusiformis	
	Thalia democratica	

Table 5.3 Comparison of Relative Abundance of Fish Larvae in the California Current Region Based on Yearly Summaries of Number of Larvae Obtained in Plankton Collections from CalCOFI Survey Cruises. (Source: Ahlstrom, 1965; rank includes only first 25.)

Species	55/#	%	Rank	56/#	%	Rank	57/#	%	Rank	58/#	%	Rank
Engraulis mordax	140,183	39.03	1	134,931	33.05	1	146,631	29.70	1	205,457	45.21	1
Merluccius productus	66,090	16.73	2	94,277	23.10	2	78,283	15.86	2	58,368	12.84	2
Sebastodes spp.	29,344	8.17	3	29,144	7.14	3	36,473	7.39	4	23,931	5.27	4
Citharichthys spp.	20,411	5.68	4	23,635	5.79	4	15,613	3.20	9	6,655	1.46	11
Leuroglossus stilbius	15,111	4.21	5	18,620	4.56	5	29,506	5.96	5	4,859	1.07	12
Sardinops caerulea	14,121	3.93	6	15,523	3.80	6	9,833	1.99	11	11,423	2.51	7
Trachurus symmetricus	13,246	3.69	7	8,027	1.97	10	20,006	4.05	6	6,409	1.41	10
Lampanyctus mexicanus	13,165	3.67	8	10.802	2.65	8	16,207	3.28	8	16,514	3.63	5
Vinoiguerria lucetia	12,654	3.52	9	9,832	2.41	9	55,114	11.17	3	55,756	12.27	3
Lampanyotus leucopearus	7,454	2.08	10	15,125	3.71	7	16,808	3.40	7	11,892	2.62	6
Diogenichthys laternatus	4,771	1.33	11	3,158	0.77	13	11,603	2.35	10	7,061	1.55	8
Bathylagus wesethi	3,245	0.90	12	2,146	0.52	17	6,347	1.29	12	7,021	1.54	9
Lampanyotus ritteri	1,988	0.55	13	1,924	0.47	18	2,789	0.56	14	3,091	0.68	13
Pneumtophorus diego	1,950	0.54	14	1,520	0.37	20	1,865	0.38	18	1,273	0.28	20
Eleotrona spp.	1,823	0.51	15	1,852	0.45	19	1,415	0.29	22	1,775	0.39	15
Bathylagus ochotensis	1,301	0.36	18	2,231	0.55	15	1,078	0.22	25	1,550	0.34	16
Melamphaes spp.	775	0.22	25	1,051	0.26	24	1,328	0.27	24	1,255	0.28	21
Cyclothone spp.	1,523	0.43	16	814	0.20		2,880	0.58	13	2,795	0.62	14
Tarlatonbeania crenularis	999	0.28	21	3.352	0.82	12	1,570	0.32	21	526	0.12	
Argentina sialis	832	0.23	24	1,288	0.32	22	1,400	0.28	23	276	0.06	
Prionotus spp.				2,470	0.60	14	2,731	0.55	15	1,307	0.29	19
Synodus spp.	641	0.18		958	0.23	25	2,338	0.47	17	1,219	0.27	23
Pleuronichthys spp.	1,038	0.29	19	1,116	0.27	23	579	0.12		164	0.04	
Diaphus theta	1,022	0.28	20	3,562	0.87	11	713	0.14		588	0.13	
Cynoscion spp.	860	0.24	23	104	0.02		31	0.06		1,350	0.30	18
Symhurus atricauda	73	0.02		1,373	0.34	21	1,603	0.32	20	.222	0.05	
Ceratoscopelus townsendi	446	0.12		222	0.05		2,598	0.53	16	1,400	0.31	17
Symbolophorus californiense	653	0.18		462	0.11		1,645	0.33	19	1,236	0.27	22
Icichthye lockingtoni	1,385	0.39	17	898	0.22		768	0.16		438	0.10	
Palmeta simillima	933	0.26	22	611	0.15		797	0.16		114	0.02	
Tetragonurus spp.	490	0.14		2,154	0.53	16	706	0.14		60	0.01	
Stomias atriventer	411	0.11		81	0.02		271	0.05		1.189	0.26	24
Hygohum spp.	400	0.11		223	0.05		795	0.16		993	0.22	25
All others	5,808	1.62		14,652	3.60		21,023	4.26		16,280	3.58	
TOTAL	359,155100			408,140		100	493,549		100	454,655		100

Table 5.3A. **Most Common Fish Larvae Collected in Surface, Shallow, and Deep Water Tows in the Southern California Bight. Source: Moser and Pommeranz (1999).**

Scientific Name	Common Name	Surface	Shallow	Deep	Total
Engraulis mordax	Northern anchovy	3066	67640	19696	90402
Leuroglossus stilbius	California smoothtongue	0	785	1401	2186
Genyonemus lineatus	White croaker	49	740	173	962
Stenobrachius leucopsarus	Northern lampfish	1	349	193	543
Sebastes spp.	Rockfish	53	264	134	451
Seriphus politus	Queenfish	17	164	106	287
Peprilus simillimus	Pacific butterfish	6	180	35	221
Paralichthys californicus	California halibut	9	82	23	114
Citharichthys spp.	Sanddab	0	63	14	77
Merluccius productus	Pacific hake	0	36	12	48
Atherinopsis californiensis	Topsmelt	44	0	0	44
Pleuronichthys verticalis	Hornyhead turbot	1	25	8	34
Eopsetta exilis	Slender sole	0	27	5	32
Bathylagus ochotensis	Deep-sea smelt	0	21	10	31
Pleuronectes vetulus	English sole	0	19	7	26
Cataetyx rubrirostris	Brotula	0	20	4	24
Argentina sialis	Pacific Argentine	0	9	8	17
Protomyctophum crockeri	California flashlightfish	0	1	10	11
Argyropelecus spp.	Hatchetfishes	0	0	9	9
Pleuronichthys spp.	Righteye flounders	0	6	3	9
Ophidion scrippsae	Basketweave cusk eel	0	1	6	7
Atractoscion nobilis	White seabass	0	6	0	6
Neoclinus stephensae	Yellowfin fringehead	6	0	0	6
Hypsoblennius spp.	Combtooth blennies	3	2	0	5
Pleuronichthys coenosus	C-O sole	4	1	0	5